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RYERSON STEEL

Metal Progress; Page 210

From a personal notebook, kept during employment in Bethlehem Steel Co.'s crucible steel department and association with the late Maunsel White, co-worker with Frederick W. Taylor in the invention of high speed steel and its proper heat treatment.

Personal Recollections of Early High Speed Steel (1904-1906)

THE DATA on the early use of molybdenum in high speed steel in the following pages have been culled from the author's notebooks, and were collected during the years 1904 to 1906 when he was employed at Bethlehem Steel Co., first as a learner, later as assistant superintendent of the crucible steel department. At that time, the manufacture of high speed toolsteel at Bethlehem was under the general supervision of the late Maunsel White, co-worker of Frederick W. ("Speedy") Taylor, and originator of what was then known as TW (Taylor-White) brand high speed toolsteel, and of modern heat treatment of high speed steel.

About 1899, a small department for the manufacture of toolsteel was installed at Bethlehem in a space adjacent to what was then No. 11 open-hearth furnace. Melting facilities consisted of some 20 coal-fired, 4-pot melting holes, with a fan to provide forced draft under the grate bars, and a stack to carry off the products of combustion. In this type of melting equipment, a hard-coal fire was first started on the bars, the charged crucibles were then put in on top of this bed of coal, and more fuel was added around the crucibles and heaped up over them. When the charge in the crucibles was partially melted, the coal was poked down around the crucibles, which were then lifted partly out of the fires and fuel worked down under them. After a further hour or two, the steel was melted and ready to pour. Two charges per day were melted in each hole.

The steel was melted in clay-graphite crucibles holding 90 lb. each, sealed by bottoms of old crucibles inverted over them to keep out the coal heaped above. Anthracite of "broken coal" size was the usual fuel, though some coke was at times used when the crucibles had been lifted the first time, in order to secure faster melting. The pot-pullers and melters of those days were a class of highly skilled men, proud of their abilities and clannish to a degree. Once get their confidence, however, and you would conclude that no finer body of men could be found.

While Fig. 1 shows a crucible being poured into a collecting ladle at the left, for later teeming into a large ingot mold or casting mold, the toolsteel ingots were quite small and poured by hand directly from the crucibles in split cast iron molds of various sizes, each size being used for a given range of size of finished steel bar. Cold ingots were heated in a coal-fired furnace of very simple design, and broken down under steam hammers, of which there were 2500 and 1500-lb. ones — also a 500 or 600-lb. "tilt" hammer used for the smallest rounds, squares and flats. The hammer men also made octagons and hexagons, the latter by making an octagon, with unequal sides, and gradually shap-

By John Howe Hall
Consulting Engineer
Swarthmore, Pa.

ing it until two of the sides disappeared. At that date, rolling of toolsteel, especially high speed toolsteel, was seldom attempted, since the industry was dominated by men trained in the Sheffield tradition, who believed that fine toolsteels must always be broken down and brought to size by hammering. The late Henry Marion Howe once told me that he knew of one Sheffield consultant who even insisted that the light hammers must be belt driven, and that good toolsteel could not conceivably be produced with direct motor driven mechanical hammers!

In the early days of the Bethlehem toolsteel department, melting stock consisted of basic open-hearth steel scrap, washed metal* and the necessary alloys. Later, under the supervision of Owen Brown, superintendent, and Frank Hoyer, melter, both former Carpenter Steel Co. men, the orthodox English practice of using low-phosphorus muck bar (puddled or wrought iron) and charcoal was established and rigidly adhered to. This was the practice the author found in use when he went to Bethlehem in July 1904, fresh from technical school. It was then that Owen Brown taught him to "grade" carbon toolsteel ingots by inspecting the fracture of the ingot after it had been "topped" — a small piece broken off with hammer and cutter. The carbon content could be estimated by this method with considerable accuracy, and this was the established means of determining the "grade" or "temper" of each ingot, chemical analysis of each ingot being too expensive even to consider. Then, as now, carbon content of the steel regulated its best use, and ranged from the so-called "hard" grade (0.60% C) for sledges and hand battering tools up through the "spring" and "cutlery" grades (about 1% C), then general machine shop tools, to razors and "high, lathe-temper" at 1.30% C.

Fig. 1 — Crew and Equipment in Crucible Steel Dept., Bethlehem Steel Co., Sometime Between 1910 and 1915. (For help in exhuming the old photographs used on these pages the author is indebted to B. H. Strom of the Publications Dept. of Bethlehem Steel Co.)

It is of interest, incidentally, that as early as 1904, it was standard Bethlehem practice to use about 0.5% chromium in carbon toolsteel to secure a finer grain and better hardening properties. For tools for finishing cuts — steels of otherwise plain carbon analysis — as much as 1% chromium was added to the mix.

Frederick W. Taylor, in his presidential address before the American Society of Mechanical Engineers in 1907 ("On the Art of Cutting Metals") notes that the "Midvale Chrome Crucible" water

*Wash metal or washed metal is the result of one of several pig washing processes — modifications of ordinary refining. It consists in treating molten pig iron with molten oxides (oxides of iron, occasionally mixed with oxides of manganese) in a reverberatory furnace. At the low temperature employed, and in the presence of the very basic slag, most of the silicon and the phosphorus are removed, the metal being tapped out before the carbon has been materially attacked. The elimination of the silicon and the phosphorus may amount to 90 or 95%. — "Iron and Steel (a Pocket Encyclopedia)" by Hugh P. Tiemann.

hardening steel had 0.73% carbon and 4% chromium; its cutting speed was 8 ft. per min. as compared with 16 ft. per min. for best Jessop (Sheffield) steel with 1.05% carbon.

The earliest Bethlehem high speed toolsteel, noted in the somewhat scanty records by the present author, analyzed a little over 1% carbon, 4% chromium, and 15% tungsten. This analysis was quite similar to that of Carpenter Steel Co.'s "Zenith" steel of that time. In Table I are shown the compositions of a number of samples of representative high speed toolsteels of the early years of the century, including "Zenith". In 1904, however, the standard "TW" analysis was still approximately what was shown at the Paris Exposition (see the first three columns in Table II) with lower tungsten than that of most of the similar toolsteels of the period.

Table I — Analysis of Typical High Speed Toolsteels of 1904

Name	C	Cr	W	Mo	Mn	Si	P	S
Zenith	1.09	5.08	14.37	—	0.05	0.178		
	0.70	3.70	15.53	—	0.04	0.153		
	0.66	2.89	24.63	—	0.12	0.135	0.01	0.008
Victoria (Oct. 1904)	0.60	7.02	24.64	—	0.03	0.205	0.015	0.013
Hudson	0.37	4.10	16.46	—	0.18	0.09	0.014	0.008
Styrian White Label	0.40	4.73	16.22	—	0.18	0.12	0.025	0.008
	0.71	4.80	16.06	—	0.13	0.08	0.016	0.020
Capital	0.32	1.85	15.29	—	0.15	0.346	0.019	0.006
	0.74	3.15	11.70	—	0.25	0.31	0.025	0.007
Novo	0.64	2.94	18.44	—	0.25	0.364	0.014	0.008
Rex AA	0.55	2.69	19.09	—	0.27	0.07	0.016	0.01
E. W. Bliss	0.98	5.86	13.78	—	no record			
Burgess Special	0.34	2.90	11.75	—	0.06	0.076	0.02	0.009
Midvale Special	1.19	3.34	7.56	—	0.46	0.20	0.025	0.024
Novo	0.57	2.87	16.04	0.90	0.16	0.14	0.027	0.02
Bischoff	0.50	3.80	10.12	1.32	(—)	0.194	0.012	0.02
Blue Chip	0.44	2.72	17.54	0.75	0.12	0.10	0.017	0.010
Burgess No. 5	0.56	4.58	16.17	0.78	0.17	0.11	0.02	0.007
Rex	0.54	3.46	—	5.32	0.12	0.33	0.021	0.021
Excelsior	0.78	4.08	—	5.58	0.03	no record		
Heller Bros.	1.20	4.46	—	6.49	0.04	no record		
Ry.*	0.46	5.61	—	10.34	0.05	0.51	0.024	0.024

*Name uncertain.

The author has no personal knowledge of the steps by which Mr. Taylor had been led to adopt this analysis, although in his A.S.M.E. presidential address (1907) he stated that in 1894 and 1895 he had investigated the toolsteel problem for the Sellers and the Cramp firms, and at that time the choice narrowed to Mushet's air hardening toolsteel (2.15 C, 1.0 Si, 1.6 Mn, 5.5 W and 0.4 Cr, with cutting speed of 26 ft. per min.) and Midvale's imitation where chromium was substituted for the manganese to avoid patent infringement (1.4 C, 0.4 Si, 0.3 Mn, 8.5 W and 1.5 Cr, with cutting speed of 30 ft. per min.). It was when experimenting with the best heat treatment of the latter for Bethlehem in 1898 and 1899 that the treatment to produce red hardness was discovered, as well as the stabilizing effect of tungsten on austenite at all temperatures, and the effect of a "judicious" selection of tungsten and chromium on the tempering reaction at 1125° F. — the transformation of some austenite to martensite. The chromium was probably increased over the Midvale air hardening analysis to enhance this secondary or red hardness. Cutting speed of this steel was 60 ft. per min.

It will be noticed that the analysis of the early

Table II — Standard and Production Analyses, Taylor-White Steels, 1900 to 1907

	Paris Exposition *(a)*	Standard TW		Standard TWS		1907 TW Standard	"Best" *(c)*
		1904	Range of 4 *(b)*	1904	Range of 18 *(b)*		
Carbon	1.85	1.30	0.92 to 1.55	0.45 to 0.55	0.28 to 0.80	0.50 to 0.70	0.67
Phosphorus	0.03		0.020 to 0.025		0.017 to 0.031	Low	Low
Sulphur	0.03		0.010 to 0.013		0.009 to 0.034	Low	Low
Silicon	0.15		0.11 to 0.17		0.035 to 0.36	Low	0.04
Manganese	0.30		0.18 to 0.20		0.02 to 0.35	0.10 to 0.15	0.11
Tungsten	8.0	8.5	8.14 to 9.22	9.0 to 10.0	8.51 to 10.35*	19.5 to 20.5	18.0
Molybdenum				2.5 to 3.0	2.92 to 4.77†		
Chromium	3.8	3.5	2.86 to 3.33	3.0 to 4.0	2.03 to 4.80	3.5 to 4.0	5.5
Vanadium							0.29

(a) First TW steel exhibited by Bethlehem Steel Co. in Paris, 1900. Cutting speed 60 ft. per min. in comparison with 16 ft. per min. for best 1.05% carbon toolsteel.

(b) From the author's notes.

(c) Quoted as "best" (cutting speed 99 ft. per min.) by F. W. Taylor in "The Art of Cutting Metals" (1907).

*Three samples ran 12.78, 13.44 and 13.52% W. †Two samples ran 6.04 and 7.54% Mo.

standard TW is not greatly different from that of Midvale Special, Burgess Special, and one of the Capital types shown in Table I. At this time, moreover, careful tests of the performance of the various high speed steels were carried out in the company's machine shops, under the supervision of trained observers, and these tests served as a guide to the most suitable compositions to make and use.

From Table I, it will be noted that — at the time we are considering — at least two types of molybdenum-bearing high speed toolsteel were being produced in this country, one type with about 1% Mo added to the conventional chromium-tungsten type, and the other type containing only molybdenum and chromium, the chromium usually being rather higher than in the conventional steels of the day.

Table III — Experimental Melts, Bethlehem, 1902-1903

No.	C	Cr	W	Mo	Mn	Si	P	S
A	1.15	2.47	16.34	—	0.24	0.182	0.011	0.023
B	1.22	2.36	16.92	—	0.32	0.17	0.014	0.03
C	1.22	2.91	16.98	—	0.30	0.22	0.013	0.022
D	1.00	2.94	16.99	—	0.24	0.283	0.013	0.020
E	0.76	2.85	19.64	—	0.30	0.09	0.015	0.025
F	0.77	5.05	6.53	—	( )	0.069	no record	
G	0.83	4.57	6.41	—	( )	0.055	no record	
H	1.18	2.90	12.96	3.63	0.32	0.252	0.015	0.030
I	0.98	1.47	7.71	2.48	0.30	0.205	0.014	0.020
J	0.74	3.13	13.52	4.54	0.15	0.36	0.009	0.023
K	0.34	6.14	9.25	7.60	0.13	0.081	0.015	0.025
L	0.32	5.04	9.16	6.37	0.10	0.065	0.014	0.023
M	0.50	3.44	10.10	4.77	( )	0.094	0.014	0.030

With a view to testing the possibilities of these various compositions, a series of melts was made at Bethlehem in December 1902 and the early part of 1903. The analyses are shown in Table III. These steels fall into three groups, one the conventional chromium-tungsten of that date, one group with rather low tungsten and high chromium, and one group containing varying percentages of molybdenum combined with different proportions of chromium and tungsten. A noticeable feature of these steels is the comparatively low carbon content, which corresponds to the practice in three out of four of the high-molybdenum compositions shown in Table I. As a result of the tests of these steels, a new grade, Taylor-White Special (TWS), as shown in Table II, was adopted. In the summer of 1904, this and regular TW were the standard grades at Bethlehem, the TWS being considered the better for most purposes.

How the analysis of different lots of these steels made in regular production conformed to the established standard is also shown in Table II. In considering the variations shown, especially in carbon content, it must be remembered that each 90-lb. charge melted at a somewhat different rate, and that the carbon varied in more or less direct ratio to the length of time the steel was kept molten, waiting until all the crucibles were ready to pour into ingots. Of course, the pot pullers could not be expected to "pull" each pot as it was ready, or they would have been waiting around in their heavy, wet "rags" for hours; their task was hard enough, anyway, in all conscience!

Carbon Control

In plain clay-graphite crucibles, there was a gain in carbon during melting, greatest in new crucibles, least in those that had been used several times. In clay-lined graphite crucibles, the carbon decreased rather than increased, except when the steel had cut through the comparatively thin lining and had come in contact with the clay-graphite body. Then, of course, there was a gain of carbon, of uncertain amount. As may be imagined, carbon control was, at the best, quite erratic. Chromium, tungsten and molybdenum content, as a rule, was more uniform. Chromium was added to the crucible in the form of the 70% alloy; tungsten and molybdenum usually as metal powder. The re-use of crop-ends of hammered bars, and of worn-out tools from the machine shops, naturally introduced a further source of error, since it was not always possible to keep the scrap correctly sorted.

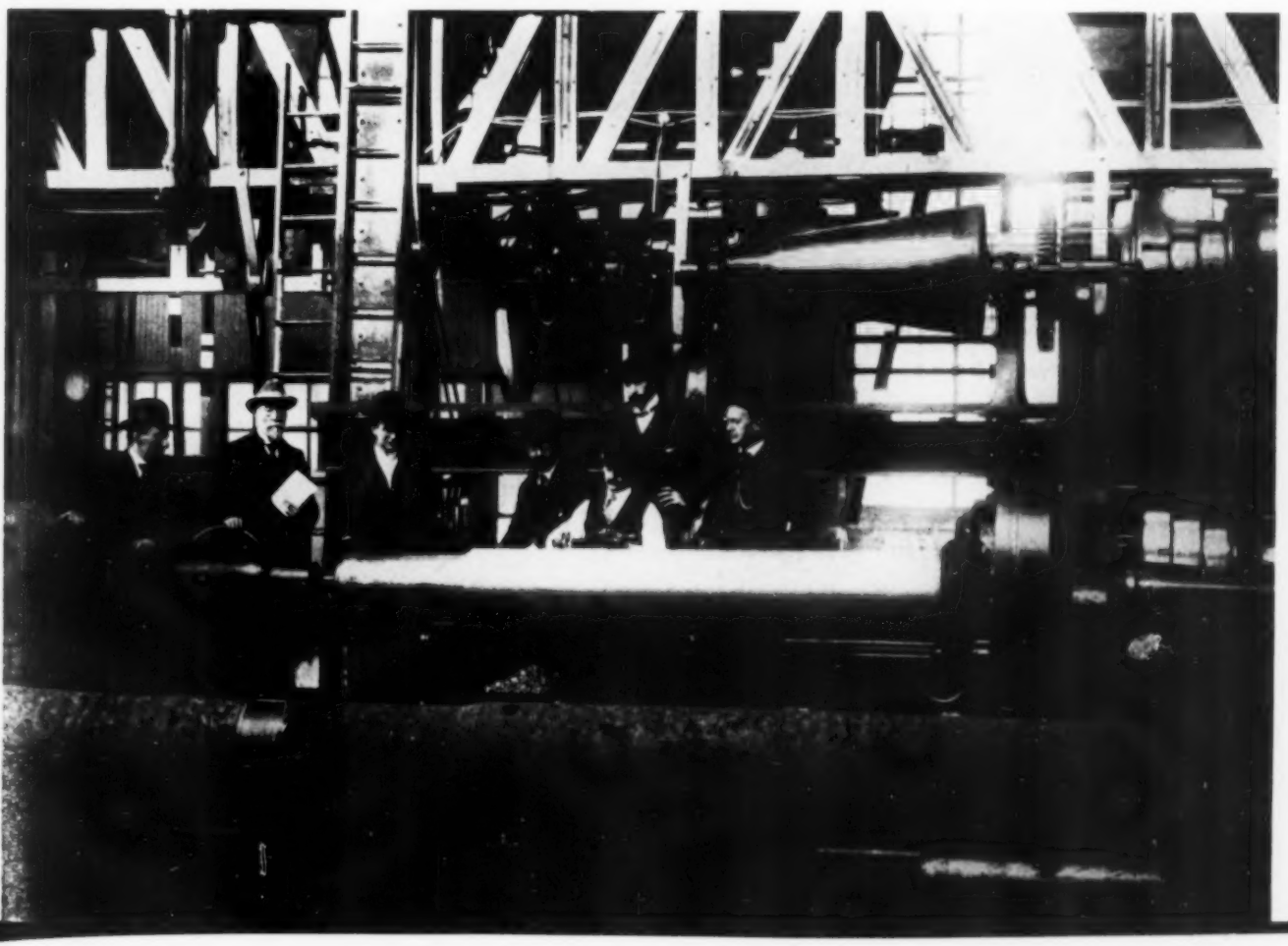
The Taylor-White Special, because of the low carbon desired, was practically always melted in clay-lined crucibles. The author recalls clearly Mr. White's oft-repeated statement that this steel should be kept "as low in carbon as possible, carbon-free, if only that were possible" — a view that would hardly pass muster today. Another vivid recollection of those days is the maledictions of the hammer men who had to produce bars of Taylor-White Special. For some reason never quite clear, this steel had an inveterate habit of developing longitudinal seams and cracks in the bars, which reached its greatest intensity in flats. Bars that had been heated and hammered with the greatest care, and laid down to cool in apparently perfect condition, would be found next morning to have developed seams, and much of the hammered bar would have to be cut off and remelted as scrap. Attempts to control the cooling rate, in those days rather primitive, were usually unavailing — the

bars cracked anyway. The author recalls the appearance of a flat bar, some $\frac{3}{8}$ x 2½ in. in cross section, that had split at one end during cooling into two sections $\frac{3}{16}$ x 2½ in., the two portions drawing apart into a Y-shape with the ends perhaps 3 in. apart like a child's sling-shot crotch. To make the matter worse, carefully inspected bars sent to the machine shop storerooms would be found, months later, to have developed seams, and would be returned to us with appropriate comment. All hands in the toolsteel department, despite the excellent performance of TWS in the machine shops, thought very meanly of the product, and used every endeavor to promote the adoption of an "18 tungsten, 4 chromium" standard.

During 1905, in connection with other improvements in the old Bethlehem steel plant, the toolsteel department was moved into the cast house of an abandoned blast furnace (old No. 1, probably) and an adjacent building, and more hammers were installed. Two 36-pot melting furnaces, fired with producer gas, and a 5-ton acid openhearth furnace were provided, the latter with the idea of producing small lots of steel of special analysis, the bane of every sales force in those days — as well as now. This furnace, however, was soon torn out to make room for other melting equipment. John E. Sandmeyer was brought from Newark as superintendent in the place of Owen Brown, and the author served as assistant superintendent until the summer of 1906. Later, George Brown, formerly of Carpenter Steel Co., had charge of this old toolsteel department for a time.

An energetic sales campaign was started, with trained men from the company's staff as demonstrators, and a sizable business soon resulted. The author participated in the further development of TW steel only until the summer of 1906, when he left Bethlehem to specialize in steel foundry practice. By January 1907, however, to judge from articles published in *The Iron Age* and other technical papers, the composition shown in the next to last column of Table II had been standardized. Later, of course, the advantages of vanadium additions to high speed steels were demonstrated, and the regular "18-4-1" composition was widely adopted in the industry. But that, and the substitution of electric melting units for the man-killing old crucible melting furnaces, is another story, which has been well told by Henry C. Bigge, present head of Bethlehem's toolsteel department, in a series of five articles in *Metal Progress* starting in October 1937.

Fig. 2 — Group of Toolsteel Experts at Experimental Lathe in Bethlehem Steel Co.'s No. 2 Machine Shop, 1907. Left to right: E. G. Tice, assistant to manager of ordnance; John W. Langley, professor of electrical engineering, Case School of Applied Science; E. O. Acker, chief metallurgist; Albert Sauveur, professor of metallurgy, Harvard University; A. Quier, toolsteel engineer; H. T. Morris, superintendent, armor department; and Maunsel White of the Taylor-White team



A Page for a Biographical Dictionary

Photo by Michnovicz

Cyril Stanley Smith

An Appreciation by a Former Associate

When Cyril Stanley Smith came to Waterbury in 1927 and joined the staff of the late William H. Bassett, metallurgical manager of The American Brass Co., none of us knew anything about him except that he was a young Englishman who had done some good work with copper. He had graduated from the University of Birmingham in '24 and had come to America and taken his doctorate at Massachusetts Institute of Technology. His earlier life is still better known to him than to us, but at the time he came among us he was already armored with the awareness that dogma and assertion do not constitute proof. A singularly mature outlook had this young man —a good foundation in physics, a swift perception and a wide range of thought. Connecticut inhabitants do not go gushing overboard with enthusiasm for a new acquaintance, but allow mutual reactions to take their natural time, yet it was scarcely any time before we discovered ourselves seeking Cyril's company for the sheer joy of it.

Soon he was delegated to organize a research department, an assignment which he accepted on condition that he "be asked to do nothing practical". At that time technical progress in the brass industry was in the doldrums. The first surge of technical application to brassmaking had run its course and caught up with itself. It was time for a fresh approach. The new research laboratory, while at first it consisted of little besides Cyril Stanley Smith himself, was qualified to perform work of a fundamental nature and provided the tonic that was wanted. His presence was an inspiration and no one could emerge from a conversation with him without feeling a fresh enthusiasm and seeing fresh vistas of possibilities in his job.

Then the icons began to fall! Quietly and without any struggle they toppled from their pedestals and slipped into limbo, and our minds were freed from many a strangling idea that we had never thought of questioning. Gradually answers began to appear for things that had been mysteries. The promise "to do nothing practical" broke down in spots. For two heartbreaking years Cyril spent much of his time at a copper refinery, and he could often be found in a casting shop, getting himself dirtier, in a shorter time, than any other young man we ever saw.

Steadily he published and discussed; he could no more keep out of print than he could sit twiddling his thumbs. (Incidentally, he is the only person we ever knew whose handwriting is utterly illegible!) His idea of a good time was to rise at 2:00 a.m. to photograph the heavens. As an avocation he translated, in collaboration with Martha Teach Gnudi, Biringuccio's *Pirotechnia*, a work antedating Agricola and vastly more original. It was Cyril who discovered, after 400 years, that whole sections of Agricola were lifted bodily and without acknowledgment from the earlier writer. The translation was an ambitious undertaking and Cyril grew thin. When at last it was done, it was batted from one publisher to another, but the appeal was considered too limited and none would take the risk. It began to look as though the book would never come out, when the American Institute of Mining and Metallurgical Engineers came to the rescue with a modest financial guarantee, and there emerged from Yale University Press the most beautiful and delightful volume that a metallurgist ever held in his hands. The jest, after all, is at the expense of the skeptics! The first edition is a book-collector's prize, it has sold out the second edition, and — best-of-all — it occupies an important niche in metallurgical literature.

Smith has an uncanny flair for digging out the origins of things; we were often amused to learn from him that processes which men were rushing about to secure by patent had been expounded long ago and forgotten again. Choosing the A.I.M.E. as the vehicle for most of his published papers, he was chairman of its Institute of Metals Division in 1943.

Having married the beautiful and accomplished Alice Kimball, a Ph.D. in her own right, and finding themselves the parents of a son and a daughter, they built a house in Cheshire. One would not expect it to be of a conventional pattern, and it wasn't, but it served more than moderately well.

Cyril applied for citizenship papers. His department of research at American Brass was firmly established and when the war came it was inevitable that he should, in 1942, gravitate to Washington. There, on loan, he served for a time as research supervisor of the War Metallurgy Committee, and next thing we knew he was in New Mexico consorting with the black art, for in the spring of 1943 he went to the newly forming Los Alamos Laboratory of the Manhattan District, to take charge of the metallurgical end of designing and building the atomic bomb. Most of the people there were physicists who had been working together on the problem previously. Cyril knew little of the problem or of its needs —

in fact he knew few of the physicists. He had few assistants and almost no equipment. However, after a very short incubation period, he assembled a group which was able to solve the problems and meet the necessary deadlines. The fact that he was able to think like, talk to and understand the problems of the physicists, translate their requirements into things that could be done, and get these things done, explains the high regard in which he is held by his associates on that project.

He left Los Alamos at the beginning of 1946, feeling that the foothills of the Rocky Mountains included the most desirable places in the world to live (except possibly the house in Cheshire), but that the world had need of more fundamental work than the building of weapons of war. He feels — more keenly than most people — the gravity of that infernal consummation, that the world will not again be the same, and that it is the scientist's duty to use every possible means to inform his fellow citizens about the nature of scientific and technical advances and how they are likely to affect their mode of life.

Events are built on what has gone before, and, of course, such a man could not decline the opportunity of founding the Institute for the Study of Metals at the University of Chicago. His recent appointment to the advisory committee to the Atomic Energy Commission comes as a natural sequence. So CYRIL STANLEY SMITH takes his place among the first metallurgists of our time. His presence in his old haunts is sadly missed, but the memory of him and his influence still pervades them. He is still a young man and we have not heard the last of him.

A FORMER ASSOCIATE

Nonmetallic Grain Boundary Material in Carburized Cases

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IT IS A COMMON OBSERVATION that carburized parts may come from the pot or quench with a discolored surface layer — ordinarily of microscopic thickness (a fraction of a thousandth). The metallurgical literature contains reports of several investigations concerning the identity of this surface layer and the cause of its formation. Microscopic examination of cross sections into such parts, on specimens carefully prepared to show conditions out to the very surface, has sometimes revealed an apparent penetration of this nonmetallic surface layer into the grain boundaries for a short distance, or its presence as isolated particles.

Metallurgists have not been in agreement as to the exact nature of this grain boundary material, nor as to the conditions favoring its formation, nor as to the physico-chemical principles governing the reactions. As to the material itself, it has been called graphite by some observers, and "oxide", a silicon compound, or an aluminum compound by others. As to the carburizing practice that is responsible, some metallurgists are of the opinion that carburizers "energized" by barium carbonate are more prone to produce this unwanted surface condition than are those "energized" with calcium compounds.

Other competent metallurgists have observed that the alloy content of the steel has a good deal to do with the presence of nonmetallic surface layers or contamination within the metallic grains after routine carburizing. For example, in the

high-chromium steels, such as S.A.E. 3312, these abnormalities include soft layers under a very high-carbon surface, and the soft layers are ascribed to low carbon content, in turn due to abnormally high oxygen content in the steel. Furthermore, in some plants the type of quench has been found to have its influence, especially when carburizing larger-than-average parts. Slow quenching in oil that is not oxygen-free may discolor a surface layer as thick as 0.0002 in.

Table I — Carburizing Mediums Used

Medium	Barium Carbonate	Calcium Carbonate	Sodium Carbonate	Sulphur	Moisture	Ash
A*	13.8	3.7	3.8	0.24	2.4	4.3
B*	6.0	3.0	0.5	0.80	0.6	7.7
C*	Trace	12.2	0.8	0.60	1.3	0.5
D*	8.0	0.2	0.8	0.60	0.2	6.0
E	Equal portions of A, B, C and D run in a small carburizing box.					
F	Similar to E, except regular production carburizing boxes were used.					
G	Charcoal (pseudocarburizing).					
H	Gas (using carburizing fluid).					
I	Gas (using natural gas).					

*Commercial carburizers sold under various trade names.

From the theoretical standpoint, those who have expressed an opinion seem to believe that the oxidized surface and the underlying zone containing nonmetallic particles or networks result in an attempt to reach equilibrium in a very complicated system between iron, carbon, oxygen and one or more alloying metals.‡ The present author has not carried out any direct work on the Fe:C:O system or any of the more complicated systems. He must therefore content himself with stating the facts derived from a series of experiments to learn something about the origin and identity of the oxidized layer and grain boundary material. These facts seem to be somewhat at variance with those published by some other investigators.

Examination of Carburized Gears

This nonmetallic material when in sufficient quantity may be detrimental to the service life of certain parts that are not ground after carburizing. This is especially true of gears, and some case failures in service have been traced back to this grain boundary condition.

In this investigation, therefore, gears were carburized in various mediums and at various temperatures. In addition, varying conditions of both carburizer and surface finish were investigated in order to study their specific effects on the

Table II — Maximum Depth (In.) of Grain Boundary Condition

Medium	Carburizing Temperature				
	1650° F.	1700° F.	1700° F.*	1850° F.	1850° F.†
A	0.0002	0.0004	0.0004	0.0017 to 0.0030	0.0010 to 0.0028
B	0.0003	0.0004	0.0005	0.0009	0.0009
C	0.0009	0.0009	0.0020	0.0021	0.0015
D	0.0009	0.0009	0.0017	0.0010	
E	0.0002 to 0.0009	0.0009	0.0010	0.0010	
F	0.0002 to 0.0009		0.0007	0.0010	
G					0.0015
H	0.0005 to 0.0010				
I		0.0003 to 0.0010			

*Carburizer was saturated with oil prior to test.
†Carburizer was saturated with water prior to test.

‡See, for example, "Carbide and Oxide in Surface Zones of Carburized Alloy Steels", by Axel Hultgren and Erik Hägglund, *Transactions* ASM, V. 39, 1947, p. 820.

Machine parts often come from the carburizing process with a light scale, and grain boundaries at the very surface outlined by a nonmetallic substance. This is a study of the operating conditions that influence this grain boundary effect, and of the nature of this nonmetallic phase.

surface microstructures. In all, nine carburizing mediums were used; their analysis or nature is shown in Table I. In all experiments the carburizing cycle was 14 hr.

The first run was made with gears of S.A.E. 2515 steel of the following analysis: 0.12% C, 0.40% Mn, 0.009% P, 0.013% S, 5.09% Ni. After carburizing by approved practices and cooling in the pot (or in the carburizing gas), a gear tooth was sectioned and carefully prepared for microscopic examination by methods that preserved the surface layers.

Table II shows the maximum depth of the nonmetallic grain boundary condition after each run. Sometimes this condition was very faint

Fig. 1 — Layer of Scale on Carburized Steel, and Nonmetallic Phase at Grain Boundaries Near Surface. Unetched; 500×; ordinary white light illumination

and occurred only as fine fingers of scale while in other instances it occurred as fine globules.

The above described tests seemed to be sufficient to determine the influence of carburizing medium and carburizing temperature on the surface condition of S.A.E. 2515 gears in production. In addition a number of runs were made in Medium A in regular production (14-hr. cycle at 1700° F.) to determine the effect of various cooling methods and of specially prepared surfaces. Conditions of these tests were as follows:

1. Direct quenched after carburizing.
2. Air cooled from carburizing temperature.
3. Pot cooled from carburizing temperature.
4. Rehardened after air cooling from carburizing temperature.
5. Sandblasted prior to carburizing.
6. Drawn at 1080° F. prior to carburizing to relieve the cold working stresses produced by machining.
7. Copper plated prior to carburizing.

The nonmetallic grain boundary material was found at the surface of the carburized cases after tests No. 1 through No. 6 inclusive — that is to say, in all except the last. The copper-plated sample of test No. 7 also showed no carbon penetration after pseudocarburizing and the nonmetallic grain boundary material was not apparent.

Steels of various chemical composition were also investigated to determine the effect of some of the more common alloying elements. Again, the carburizing cycle was 14 hr. and the carburizing temperature was 1700° F. Results follow:

Steel Type	Depth of Boundary Condition
1050	0.0010 in.
8724	0.0008
2515	0.0006
4320	0.0006
9260	0.0004
1010 (rimmed steel)	Nil

The above figures are the average results of at least three different heats of steel of the types noted in the above list.

Microscopic Examinations

The extent of the grain boundary condition, and the relation of operating variables having been determined in the above manner, we next turned our attention to the nature of the nonmetallic material or materials on the surface and between the grains. Metallographic studies were made under ordinary reflected white light, polarized light, and dark-field illumination. Various chemical etchants were also used to identify the constituents.

Microscopic examination of the carburized cases with ordinary reflected white light revealed a layer of light gray surface scale and a nonmetallic material in the grain boundaries. This grain boundary material had the same appearance as the massive scale at the surface and appeared to emanate from it. Unetched sections transverse to the carburized case are shown in Fig. 1 and 2 at 500 and 3000 diameters magnification, respectively.

Under polarized light the massive scale at the extreme surface was found to be isotropic, translucent, and red in appearance. The massive scale adjacent to the metal surface was found to be isotropic and opaque. The grain boundary material was found to be anisotropic, translucent, and very light yellow in appearance.

When viewed under polarized light there was a difference in appearance between the outer surface layer of massive scale and the layer of massive scale adjacent to the metal surface. The grain boundary material also appeared to be dif-

ferent from the massive scale in either the extreme outer layer or the layer immediately adjacent to the metal surface.

Incidentally, a difference was noted in the surface appearance of gears carburized in different mediums. Some produced gears red in appearance while others produced gears black in appearance.

Some of the reddish appearing material was scraped from the surface of a gear and sprinkled on the surface of an unetched, polished metallographic specimen. Some jewelers' rouge (Fe_2O_3) was sprinkled on another specimen. Examination with polarized light revealed the jewelers' rouge, the scrapings from the reddish appearing gears, and the outer layer of massive scale to be very much alike — that is, isotropic, translucent, and red in appearance.

Similar investigations were carried out on the dark opaque scale adjacent to the metallic surface. It closely resembled Fe_3O_4 or FeO, as checked by the appearance of scrapings from the black surfaces of some of the gears and of specially prepared Fe_3O_4. (The Fe_3O_4 was prepared in the laboratory by boiling a polished steel specimen in a solution of KNO_3 and NaOH.)

These observations under polarized light indicated that the iron oxide containing the greatest proportion of oxygen (Fe_2O_3) comprises the outer surface of the scale. Next underlying were iron oxides containing lower oxygen concentration, presumably FeO at the iron interface and Fe_3O_4 midway in depth. The phases existing in the nonmetallic layer were therefore the same as exist in scale forming in ordinary heating furnace atmospheres, ranging from Fe_2O_3 at the outer surface, passing through Fe_3O_4 to FeO at the inner surface next the metal.

As to the intergranular material, it is well known that evidence of the existence of anisotropic character should not be based on observations of thin elongated inclusions. Thus the recorded observations of the anisotropic behavior of the grain boundary material are questionable; direct identification of this material was made by examination under dark-field illumination, whereupon the massive scale at the scale-metal interface and the grain boundary material appeared to be very much alike. This is shown in Fig. 3 to 5, photographed from a section tangent to the surface of the case using, respectively, the three types of illumination. This section was ground so that a small amount of the inner layer of surface scale was retained, and the grain boundary material was exaggerated and could be studied more easily.

The identity of the massive scale and the grain boundary material was further verified by the tests for inclusions in iron and steel as given in the "A.S.M. Metals Handbook". The massive scale and the grain boundary material were both etched out after a treatment in 5% hydrochloric acid for 5 min. A stannous chloride etch produced the same result. This indicates that the massive scale and the grain boundary material behave very much like oxides of iron.

Summary

The nature and extent of the grain boundary condition was found to vary as follows:

Carburizing at a higher temperature produced this condition to a greater extent.

Mediums energized with either calcium or barium produced this condition with only slight differences when used at the same temperature.

Fig. 2 — Layer of Scale on Carburized Steel, and Nonmetallic Phase at Grain Boundaries Near Surface. Unetched; 3000×; ordinary white light illumination

Carburizing in mediums saturated with oil or water showed no definite increase in this condition.

Direct quench or delayed (air cooled) quench showed no change; subsequent heat treatment was ineffective in erasing the existing condition.

Gas carburizing and pseudocarburizing in charcoal produced this condition.

Sandblasting the original surface, or prior drawing at 1080° F. to relieve the machining stresses, showed no effect on this condition.

the network below the scale is probably a continuation of the same material.

It appears that the extreme metal surface oxidizes during the carburizing cycle. This action is accomplished by the introduction of oxygen into the metal surface and results in the selective attack along the grain boundaries.

The absence of this grain boundary material at the extreme surface of carburized parts made of rimmed steel may be attributed to the extreme

Carburized Gear Tooth Ground and Polished Tangent to a Curved Surface so as to Retain a Patch of Massive Oxide and Exhibit Oxidized Grain Boundaries. Three views of same area under three illuminants. Unetched sample, 400×

Fig. 3 — Reflected White Light

Fig. 4 — Polarized Light

Fig. 5 — Dark-Field Illumination

N.E. 9260 steels of high silicon content (2%) showed no increase in this condition.

This condition was entirely absent in steels of low silicon content (1010 rimmed steel).

This grain boundary material was identified microscopically and by etching to be an iron oxide.

Discussion and Conclusion

A nonmetallic grain boundary material was observed at the extreme surface of almost all carburized cases to a greater or less extent. The depth to which this grain boundary material extended increased with higher carburizing temperatures. Other variables in the carburizing operation appeared to have lesser effects.

The results of this investigation indicate that the massive scale at the surface of carburized cases is a combination of oxides of iron and that

abnormality of the cases obtained ("abnormality" in the sense of the McQuaid-Ehn test). It appears that very abnormal cases can absorb much oxygen directly in solution in the iron, in preference to oxidizing the grain boundaries. For this reason, very abnormal cases have a lesser tendency to show this grain boundary condition.

In most carburizing processes, the nonmetallic grain boundary material described does not exceed a maximum depth of 0.0010 in. However, depths of 0.0020 to 0.0030 in. have actually been found in production operations. Sometimes this condition exists only as fine fingers, and in others it appears as fine globules within the metal.

The depth to which this grain boundary condition could extend without being harmful depends upon the amount of metal removed during the finishing operation after carburizing, and the actual working conditions of the finished parts.

Critical Points

By the Editor

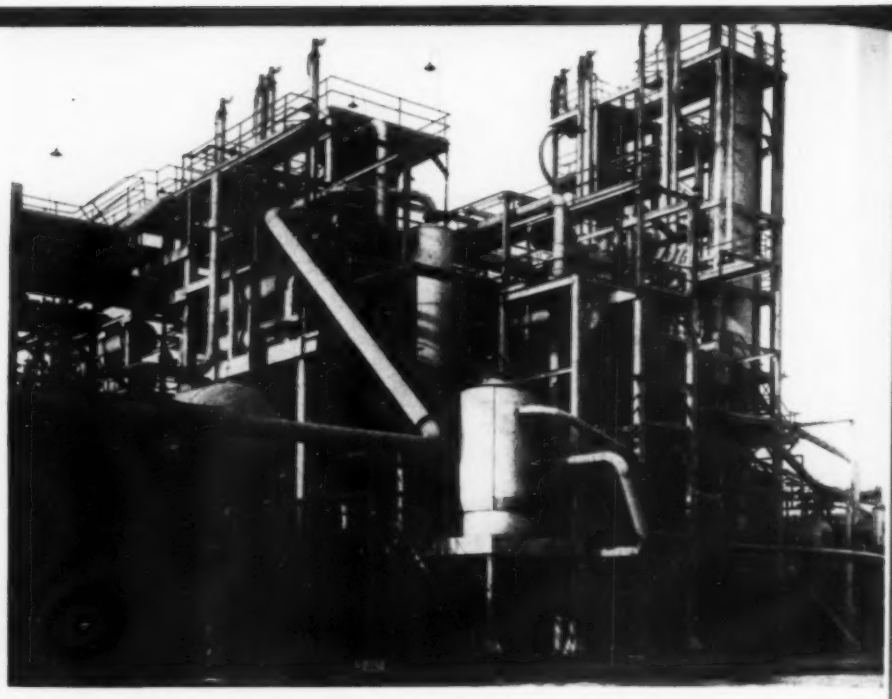
Metallurgical Monuments

IMPRESSED again, on reading proof of Dr. Condon's article on "Science and the National Welfare" in the last issue of *Metal Progress*, with the statement that American science has depended largely on fundamental discoveries made by Europeans, and wondering if that were true of metallurgy. Maybe the question cannot be answered directly, for we look upon metallurgy as a fusion of science, technology and art, and Dr. Condon admits that as a nation we have been outstanding in *applying* science. But the Editor is so often irked by hearing unwarranted praise blanketing foreign metallurgical industry and products that it might be well to look at the recent record. That may be done by examining the schedule of happenings — metallurgical milestones in America since 1917 — contained in the January issue.

A cold and fishy eye could hardly fail to see four fundamental contributions by Americans in that period, and two, perhaps three, are certainly "scientific" rather than "technological". One is the invention of coreless induction heating by Northrup (1917) so ably commercialized by Clamer's Ajax companies and the Ohio Crankshaft Co. The second is the rolling of metal with forward and rear tension by Steckel in 1922, and its adaptation to the continuous sheet mills by Tytus in 1923. The third is the explanation of age hardening by Merica, Waltenburg, Scott and Freeman (1919), the mechanism responsible for the strength of most of the present-day structural nonferrous alloys, and predecessor of Jeffries and Archer's more widely known slip interference theory of hardening (1922). Fourth is the work of Davenport and Bain (1930) on isothermal transformation that clarified the whole process of steel's heat treatment, an achievement undimmed by the fact that somewhat parallel work was going on in England at the same time. Nor is it proper to say that each of these stemmed from earlier discoveries — what discovery isn't so influenced?

Some others would be included were not the list confined to the last 30 years. For example, outstanding is the discovery of the heat treatment that gives tungsten-chromium toolsteels the quality of red hardness by Taylor and White in 1898. Another invention is Cottrell's electrostatic method of precipitating fume or vapor from gas. This was achieved in 1908, and nearly concurrently by Sir Oliver Lodge in England; it, together with the flotation method of concentration — a foreigner's invention but an American development — has saved the life of the copper-lead-zinc industry. Likewise in welding, the fundamental American discovery was by Thomson (resistance welding, 1885). More recent perfection of shielding atmospheres and slags have been much disturbed by commercial maneuverings, yet this should not prevent recognition of the importance of Langmuir and Weinman's discovery of atomic hydrogen welding in 1926 or of the submerged arc process by Robinoff, Paine and Quillen in 1927. And then there is the matter of aluminum-killed steels (about 1900) which have led to grain size control — as American as pumpkin pie.

Since three of the four recent discoveries of indubitable importance occurred at the beginning of the period under survey, it is probable that our near perspective prevents a fair appraisal of other candidates for the Hall of Fame. (Another thing that warps the view is the Editor's ignorance of those important recent happenings on the borderlines between metallurgy and chemistry, physics and electronics.) A future historian might well rank the electrolysis of magnesium brine (1919) and sea water (1941) by the Dow organization, plus all the work on the wartime projects for getting magnesium by other methods, as a turning point in the world's metallurgical industry; at present it is hard to judge the dependence of magnesium electrolysis upon Hall's fundamental discovery of the aluminum reduction process in



Underwood & Underwood

1886. . . . Nor is it well to minimize the importance of a long line of aluminum alloys for specialized properties, formulated and produced by Alcoa's staff — especially Dix's invention of "Alclad" (1927) and the continuous chill-casting of alloy ingots by Ennor (1935). Indeed the list of important alloys devised by Americans is impressive, yet here the process seems to be largely one of systematic search along traveled highways, except for the invention of the nickel-chromium heat resistors by Marsh and the cobalt alloys ("stellites") by Haynes — but both of these occurred before the period under review. A more recent exception might be the discovery that silicon is an exceedingly good addition to chromium steels to enhance heat resistance (Johnson in 1917 and Armstrong in 1919). Likewise the many important uses of molybdenum devised by numerous investigators justify the enthusiasm for the "American alloy" shown by Wills and Chandler of Ford's metallurgical staff 'way back in World War I days.

In heat treatment there is a regular procession of devices for preparation and use of protective atmospheres — all together representing as important a technological advance as could be imagined, yet none involving much more than adaptation of known mechanical and chemical processes to this specialized use. One exception might be recognized: Wilson's heater elements made of radiant tubes (1934). Finally, the recent clarification of the concept of hardenability of steel, wherein the names of Jominy, Grossmann, Shepherd and Boegehold loom large, may eventually be regarded as an achievement of first importance to the art and science of metallurgy.

Choosing these all-American developments has something in common with choosing the all-American football team. If you don't like the selections, make a new list for yourself! But it is sure that your list will add up to the same total: In 30 years, some four fundamental discoveries of great importance; eight or nine unexampled technological advances. That list may not be a long one for all the metallurgists in the U.S.A.; it might well have been better if we had done a lot more fundamental work in the science of metals — but, without being too self-congratulatory, show us another nation that has done as well.

New Corrosion Resistant Alloy

AT READING, PA., home of Carpenter Steel Co., heard a fascinating story about the quest for a strong ductile alloy to resist hot sulphuric acid throughout the entire concentration range. Sulphuric is a very devil for corrosion, especially when contaminated with minor impurities like iron, sulphur or chlorine compounds, yet it is a reagent omnipresent in chemical processes. Especially was the need acute during the war in the vast expansion of explosives manufacture, of high octane gasoline and of synthetic rubber plant. As we were reminded by D. E. Jack, vice-president of Duriron Co., the cast 14½% silicon-iron (Duriron) has been produced since 1912. It has most excellent resistance to sulphuric — in this respect it well supplements lead, the only suitable metal known prior to that time, over which Duriron has the advantage of strength but the disadvantage of nonmachinability and fragility against mechanical and heat shock. Consequently his firm for about 20 years has been progressing through a series of so-called Durimet alloys, in general by decreasing the silicon and carbon and putting in more and more nickel and chromium. The result, on the whole, left something to be desired, for these alloys lost corrosion resistance in hot sulphuric solutions nearly as rapidly as they gained malleability.

Some years ago Mars Fontana in DuPont's experimental department was turned loose on much the same problem — specifically to find a strong, forgeable, machinable, weldable alloy that could be used with cast Duriron and other alloy valve bodies, and for hardware in sulphuric acid plant, and still be considerably cheaper than the precious metals or the high-molybdenum Hastel-

alloys — the then only known forgeable metals that could survive in this service. Fontana's alloy, Dupont FA22, was the transition stage to Durimet 20 and Carpenter 20, the cast and wrought varieties now commercially available.

Their composition represents a clever example of alloy building: The several commercial variations of 18% Cr, 8% Ni have but fair resistance to hot impure sulphuric acid; in the improved alloy the chromium was retained — even increased a little — for its resistance to oxidizing contaminants such as nitric acid. Nickel, known to be the best single addition to iron for sulphuric acid service, was run up to 29%, giving a fully austenitic alloy which has maximum solubility for copper (3% or more). Copper in solid solution is known to aid in resisting sulphuric acids, but if present in a separate phase, it will readily be dissolved out and contaminate the liquids being handled. (Copper as a second phase also ruins malleability.) At least 2% molybdenum is added for its aid against pitting type of corrosion and its ability to induce a passive surface. Carbon is kept at 0.07%, the lowest practicable limit.

Such an alloy, completely austenitic in structure, has the excellent physical properties and reaction to cold work of 18-8; on the other side of the picture it is susceptible to intergranular corrosion unless, after welding, it is quenched from 2100° F. At 175° F. (80° C.) the 60° Baumé acid is the worst of all concentrations; it attacks alloy 20 at the rate of 0.040 in. per year. Good though this rate is in comparison with 18-8, it is still some 10 times as fast as Duriron is eaten away in the same acid environment, and 40 times as fast as Hastelloy alloy B. This is the present price of malleability. And as to dollar cost in plate form: 18-8 costs about 30¢ per lb., Carpenter 20 about $1.35, Hastelloy alloy B about $2.90.

Thousands of tons of Durimet 20 castings were made by the Duriron Co. and five licensed foundries during the war; Carpenter Steel Co.'s role in the development has been to apply a store of knowledge about surface preparation, heating, forging and rolling of alloys of the stainless family to this somewhat more refractory analysis. Berton DeLong, vice-president of Carpenter, pointed out some of these manufacturing practices. The new alloy is melted in coreless induction furnaces, cast into slender ½-ton ingots and cooled completely in the mold. A long reheating prepares for breakdown under a steam hammer; square billets are ground all over, reheated and rolled to bars, strip and sheet in the ordinary way.

At the Carpenter plant stainless alloy ingots are either hammer-forged or broken down in rolls (depending on experience that gives optimum results); most of them are then rolled into rounds and completely scalped in special lathes. Some of the tough alloys machine under squealing protest; DeLong says the great commercial advantage of machining over grinding is that the 5% of metal removed is good scrap for remelting.

Fundamentals of Creep

ENGAGED, while at a meeting of kindred souls at the National Bureau of Standards, in a lively and generally destructive critique of present methods of testing metals for their suitability for high temperature service (perhaps that last phrase should have stopped with the word "metals") and came away with the feeling that the great mountain of data so far acquired gives little guidance for future improvement, having heard little to shake my belief or prejudice that tests on alloys of complex structure, no matter how important these alloys are commercially, are not as likely to divulge fundamental principles as tests on simple single-phased metal, no matter how unimportant commercially. "Yes, but what metal is simple?" you may ask. "No metal is simple," is the reply, "but at least lead or silver or gold or aluminum or zinc, of near spectroscopic purity, is simpler than high speed steel." . . . . And so was reminded of a wartime visit to the research department of American Smelting and Refining Co., at Barber, N. J., where I saw a large room under accurate temperature control, full of machines for creep tests on lead and its various hardened alloys. Even at that time some samples had been under test for 10 years. Here, then, would be a chance to check up on my ideas. Lead is a metal that can readily be purified to a superlative degree; its melting point is so low that "room temperature" is to lead what "elevated temperature" is to stellite (for example); the problems of uniform test temperature are therefore reduced about to zero. . . . . To pursue that inquiry, Albert Phillips, manager of A. S. & R. research, was asked a direct question about such a "simple" metal: "Are the results of your extensive tests, as well as those in literature, sufficient to enable you to describe with considerable assurance the mechanism of creep in a single-phased metal?" The answer was, "We have not as yet been able to determine clearly any basic principles from our tests." . . . . So where does that get us? Simply here: If long and intensive study of a "simple" metal has not yet revealed general relationships — due, possibly, to small differences of initial grain size, internal strain, rate of recrystallization, and other more obscure conditions — how much more difficult will it be to deduce principles from multiphased

alloys of complicated chemical composition! These tests on lead have proved some facts, however, of negative import: There is no correlation between creep and tensile strength. If one of two alloys, A, is superior to the other, B, at one rate of strain, that is no reason to suppose it will be superior at another rate of strain. Finally, long-time performance cannot be extrapolated from short-time creep data.

Education and Research

RECOLLECTING, each year, on coming away from the National Metal Congress, what a *big* thing any effort grows into — any effort that attempts to feed out information to an apparently unlimited number of Americans of unexpected intellectual curiosity. Yet was never so impressed with the sudden increase in demands for education as on visits to Winnipeg and Chicago last autumn. Up in the great flat prairie land of central Canada, where the wheat fields spread out as a giant checkered fabric, endlessly, and where one would think farming would be the prime interest of the Canadians (they are "Americans" too) who live there, you actually find that the University of Manitoba has moved seven miles out from cramped city buildings into a spacious but little-used agricultural college, and that the *engineering* college is the one most vigorously expanding, literally bursting its seams while it awaits its new building, meanwhile making shift in huts and barracks erected during the war for soldiers' use. . . . . And at Chicago, do you know that in the last seven years, Illinois Institute of Technology (formed in 1940 by merging Armour Institute and Lewis Institute) has grown to an enrollment of 8400? The sheer number amazes one whose own engineering education was acquired in a "leading" school with all of 300 students; 8400 is many more than the hugest of the state universities had in those days. And all of them studying some branch of engineering! An ambitious project is well along toward clearing out a 100-acre slum that has gradually encroached on the 50-year-old buildings of the old Institute, and erecting a group of most modern buildings of functional type. Already new structures house Metals Research, Engineering Research, Chemistry, and Metallurgical Engineering. There is little doubt that the project will be completed, for the Board of Trustees reads like a list of top Chicago industrialists — most of them Armour or Lewis grads.

Browsing around in some old publications of the A.S.M.'s predecessors, found that one of the ideas advanced was that the Society should establish a laboratory for the study of problems submitted by members. Probably the only thing wrong with that was that the idea was one generation ahead of the times, judging from the later success of Mellon, Battelle, and the various research departments in the large universities and engineering colleges. At Illinois Institute of Technology, for example, is the 11-year-old Armour Research Foundation, already grown to nine divisions with a staff of 445 (William E. Mahin heads Metals Research), a record of about 7000 completed studies for some 1900 sponsors, and a 1946 income of $2,100,000. . . . . Research, in fact, seems to have snow-balled like education.

Also in the Chicago region, International Harvester Co. has recently established a "manufacturing research department". Harvester is by no means backward in applying advanced engineering to its plant operations, yet the new department is a recognition of the fact that some studies cannot well be made in a production plant — notably to formulate standards for operations conducted at several centers and to consider organizational and management problems. Even the techniques of manufacturing can often be given more thorough consideration in a separate place where alternate production lines can be put into operation, side by side, and their relative performance assessed without endangering the steady flow of parts and materials through associated manufacturing departments. Such, in brief, are the targets set up for the new Harvester department to shoot at. Housed in a fine and spacious building acquired from War Assets Administration, backed by forward-looking top management which has abundant past evidence of the profits that spring from modernization, such an establishment is insurance that Harvester's goal of "building the best possible products in the most economical way" will be continuously approached.

Two Corrections

ERRORS in drawings seem to be much harder to discover than errors in text. That is the only excuse THE EDITOR can think of for the mistake in Fig. 7 of John McCabe and W. H. Sharp's article (p. 807 of the November issue) wherein the legends for "germinated" and "germinated and shot-peened" are interchanged.

A second inexcusable error occurred at the top of the Table of Contents in December (p. 961). The extraordinarily fine diffraction pattern on the front cover was dubbed an "X-ray pattern" whereas it is an electron diffraction pattern made in a Type B R.C.A. electron microscope.

The first brief portion of an extended survey of wartime developments in the spot welding of aluminum alloys.

Macroscopic Examination of Spot Welds in Aluminum*

A LENGTHY REVIEW of wartime developments in the spot welding of aluminum has been prepared at the request of the Editor of *Metal Progress*. All who are acquainted with the problems involved know that a very large amount of work was done in research laboratories connected with universities, producing industry, equipment manufacturers, and aircraft builders, much of it financed by the National Advisory Committee for Aeronautics or the Army or Naval Air Forces. Most of the results of these researches have now been declassified and published; however, the volume and scattered location warrants a systematic round-up of the new information. No less than 67 publications have been examined; the author has also had direct assistance from several of the principal investigators and from his associates in the Naval Air Material Center. The extent of the present review requires its presentation in sections, of which the first, occupying the next four pages, will deal with macroscopic examination.

Macroscopic Examination

Macroscopy and radiography reveal much the same features of spot welds. However, each is better for certain details than the other and both are necessary for a complete understanding.

Macroscopic examination of spot weld cross sections was the tool used by the first researchers who studied the metallurgical characteristics of the process. While radiography has supplanted it for certain purposes, direct visual examination is still the most important means for studying aluminum spot welds. It is true that nobody can do intelligent inspection or improve the quality of spot welds without a thorough understanding of their macrostructure. Its importance is proved by the fact that most of the articles reviewed for this work used it or referred to it.

The work in macroscopy which laid the foundation for a good portion of the wartime progress in spot welding was done by Hess and his associates at Rensselaer Polytechnic Institute (reference No. 1) and by Smith and Keller of the Aluminum Research Laboratories (reference No. 2 and 3).

Professor Hess's was the first paper and its conclusions will now be considered. The method of preparing samples of aluminum alloy 24S for microscopic examination described in reference No. 4 was recommended for studying spot welds in the commercial aluminum alloys with the proviso that the spot weld be sectioned a little short of the faying surface, so that when preparation is complete, the surface under examination will be on a full diametrical area. The importance of

*The opinions or assertions contained in this article are the private ones of the writer and are not to be construed as official or reflecting the views of the naval service at large.

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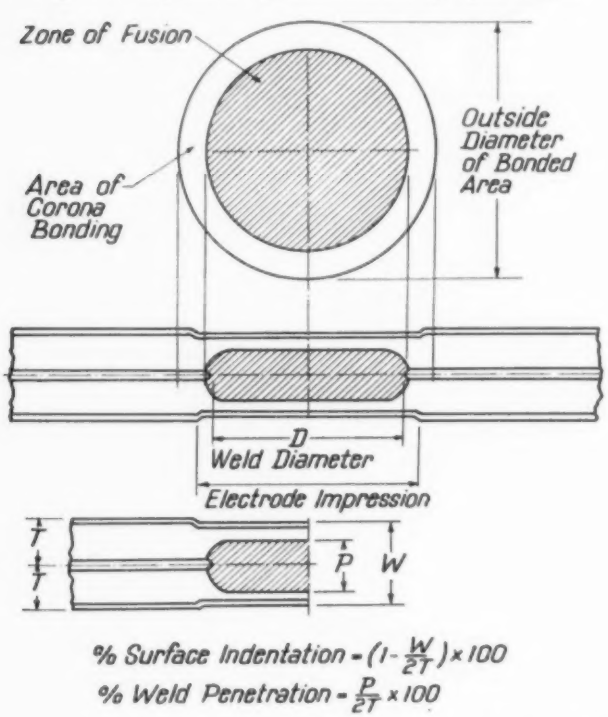
proper preparation of these samples cannot be overemphasized. The following example illustrates this.

The inspection department of a large aircraft company was rejecting a very large proportion of the welded production, purely on the basis of macroscopic examination. The spot welds showed excessive porosity, manifested as numerous small blowholes, and a great prevalence of what appeared to be a crack near the periphery of the weld in the faying plane. Strangely enough, these welds were all radiographically sound! Investigation revealed that, in order to save time, the macrographic specimens were etched with what was described as a "concentrated Keller's etch". When some of the previously rejected spot welds were repolished and etched properly as recommended by Keller (reference No. 4), there was no porosity, and the long crack was revealed as an inclusion. It was necessary to examine the section at 250 diameters to establish the identity of the inclusion.

What this story proves is that overetching causes a disproportionate attack on the interstices of the dendrites, which makes the surface appear spongy or even porous. Another thing to be remembered in the examination of spot welds is that porosity will *always* show on a well-made radiograph. Thus, if the radiographs show sound metal and macroscopy reveals porosity, there must be something wrong with either the macroscopic or radiographic technique.

Fig. 1 — Definition of Dimensions of Spot Welds



The easiest thing to see in macroscopic examination is the size and shape of the spot weld nugget or "slug", as it is called. This should be symmetrical around the faying plane and have the form of a rough oval. The penetration should be 40 to 80% of the combined thickness of the two sheets. The term "penetration" refers to the length of the transverse short axis of the slug. Figure 1 defines the penetration on a model weld.

The size of the spot weld is determined by the length of the longitudinal axis of the cross section; this is its diameter. Also, it has been established that there is a mathematical relation between the

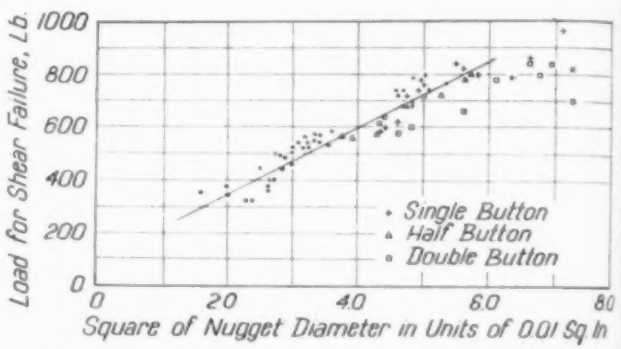


Fig. 2 — Static Shear Strength of Spot Weld Versus Area of Weld Nugget at the Faying Plane

shear strength of the spot weld and its size, as measured in the above manner. Hess and his coworkers (reference No. 1) were first to remark on this relation. The formula

$$S = 17{,}500\ D^2$$

was set up, in which S is the shear strength (load for shear failure in pounds) and D is the diameter of the slug's cross section in inches. Figure 2, from reference No. 5, shows actual shear strengths plotted against weld diameters. A straight line represents the general trend, especially in the thinner sheets with their smaller welds. This indicates that the load for shear failure is proportional to the size of the spot weld, even though the line does not correspond to the constant in Hess's formula.

Nature of Weld's Structure

The slug itself is composed of two distinct volumes (areas in the cross section), one within the other like the yolk and white in a hard-boiled egg. The outer is called the columnar zone, for its crystals appear as columns or rods reaching inward from the nugget's edge, and the inner is called the equiaxed zone. To assign the term dendritic exclusively to either of these zones is a mistake, since the crystals of both are dendrites.

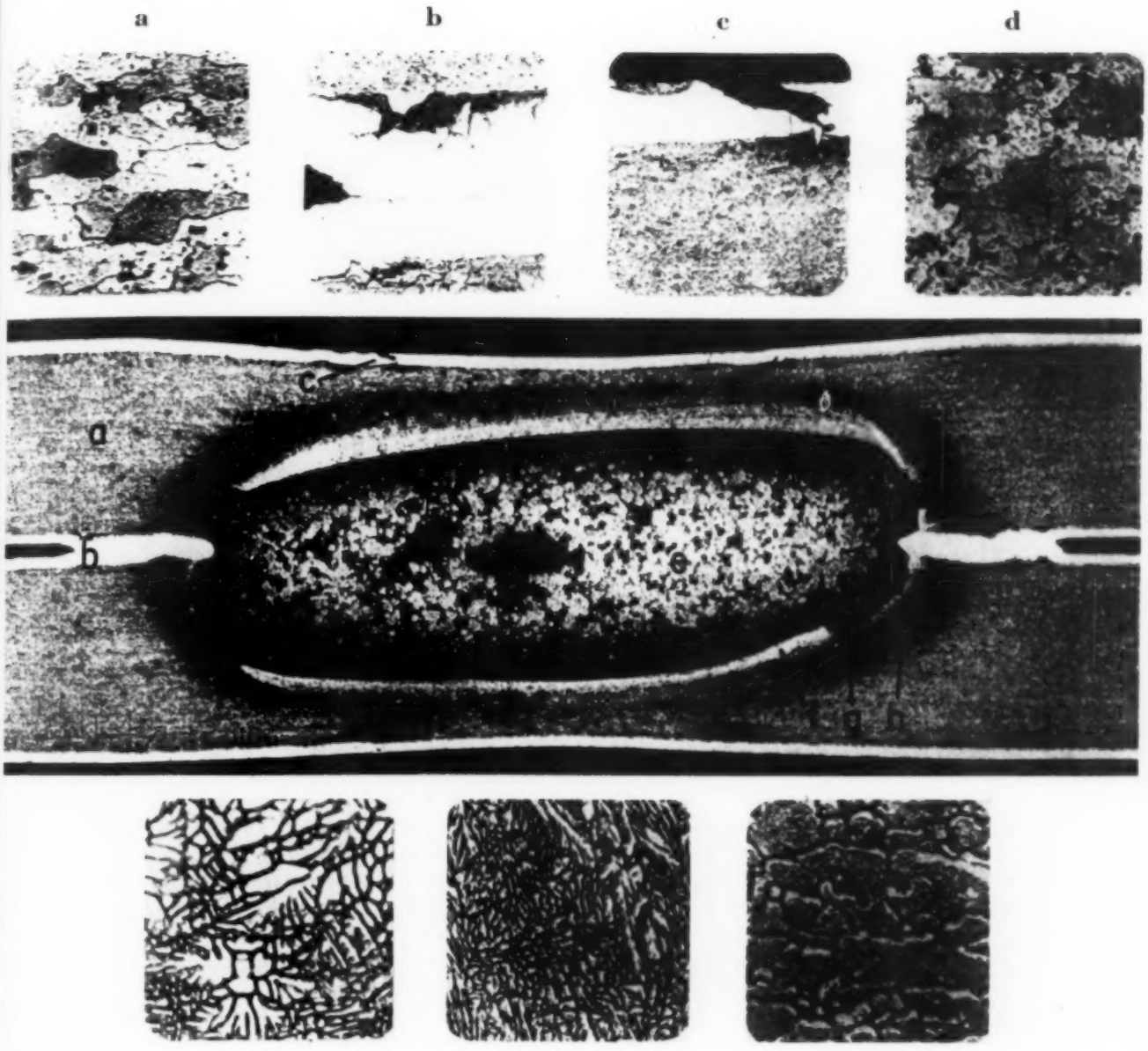


Fig. 3 — Spot Welded Slug Cut Perpendicular to Faying Surface (at 15×) and Microstructures at 500× of Regions Indicated. Original photomicrographs by courtesy of F. Keller, Aluminum Co. of America

Hence, in this review, they will be referred to as the columnar and the equiaxed. Views e and g of Fig. 3 from reference No. 2 show these two areas at 500 diameters magnification.

Spot welds in all the copper-bearing and zinc-bearing alloys of aluminum — for example, 24S-T, R303-T, and 75S-T — have very similar structures. These alloys always have a great deal of undissolved compounds in the interstices of the dendrites. Since these segregated compounds are the components which harden the metal when distributed more intimately throughout the microstructure, it follows that the "cast" metal of the slug is weaker than the unaffected sheet metal (wrought and heat treated), for if they are to be hardeners, the compounds must be uniformly disseminated throughout the aluminum. Reference No. 6 reports the results of Vickers microhardness tests on a cross section of a spot weld and the adjacent metal. The hardness number of the unaffected metal was 142 ± 1, while the hardness of the columnar zone in the slug itself was 109±2, and of the equiaxed zone it was 97±2.

It is known that 24S-T alloy, after quenching from the solution treating temperature, gradually becomes harder by a spontaneous precipitation of hardening constituents. Professor Hess and his associates at Rensselaer Polytechnic Institute ran experiments to see if there were a similar strengthening of the spot weld slug, and reference No. 7

reports the results. The shear strength of a group of welds plotted against time after welding is shown in Fig. 4, from that reference. There is hardly any noticeable improvement. This is not surprising, in view of the fact that the hardening components are mostly in the grain boundaries of the dendrites.

Because of the high temperature surrounding the molten nugget at the instant the spot is welded, temperatures above the melting points of the easiest-fused eutectics are there attained. This

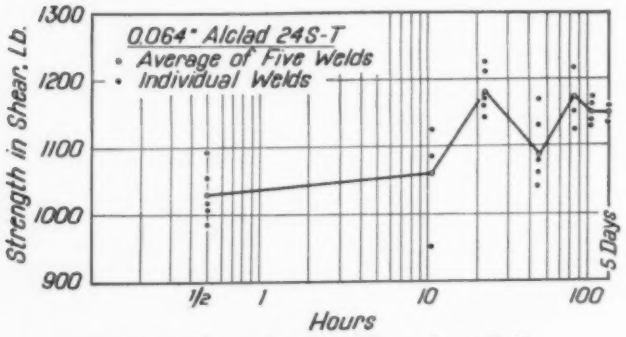


Fig. 4—Shear Strength (Pounds at Failure) of Spot Welds in Alclad 24 S-T Versus Time After Welding. (Reference No. 7)

causes fusion in the grain boundaries, as is shown in micros d and h of Fig. 3. These eutectics in the grain boundaries embrittle the metal adjacent to the weld.

Alloys like 2S, 3S, and 52S are not so susceptible to segregation of their components. Accordingly, there is no great concentration of impurities in the dendritic interstices of spot welds in these alloys; furthermore, eutectic melting in the grain boundaries adjacent to the weld is rare. Spot welds in 52S are much more ductile than spot welds in 24S, and reference No. 1 says that the presence of brittle segregation is the cause of the lack of ductility in 24S spot welds, and spot welds in 52S are not nearly so brittle for the contrary reason.

Most welds have some joining of faying layers immediately surrounding the slug. There was insufficient current at this border to fuse metal, but enough heat and pressure for something like a forge weld. This annular zone is called the corona. It takes on special meaning in alclad sheets, since it is then a bond between pure aluminum surfaces. The following remarks refer to the corona on spot welds between alclad sheets.

The relation of the corona to the rest of the spot weld is shown in Fig. 1 from reference No. 8, both as it appears on the faying plane, and on a transverse section such as is used in microscopic examination. The corona contributes to the shear strength of the spot welds, but does very little for the strength in direct tension, as measured by the "U tensile test", to be described in a later section of this report. Various investigators cannot agree as to the importance of the corona.

Occasionally, some unassimilated alclad metal will project into the columnar zone from the edge of the slug. If this projection is of any great extent, it weakens the slug, since it effectively increases the area of the corona at the expense of the slug's area, and the corona is much weaker than the metal in the slug.

Porosity, or holes, is not a very serious defect in the nugget, chiefly because it always occurs in the equiaxed portion. Cracks, however, are more serious, particularly if they approach the edge of the sheet.

If the slug projects through the alclad layer to the outer surfaces of the sheets, the resistance of the metal to corrosion has been seriously impaired. The same is true if the slug only touches or is part way through the alclad layer.

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8. "An Investigation of the Spot Welding of Aluminum Alloys Using Condenser Discharge Equipment Provided by the Taylor-Winfield Corp.", by W. F. Hess, R. A. Wyant and B. L. Averbach. Rensselaer Polytechnic Institute Report No. 5, *Welding Journal*, August 1945.

This is the first portion of a manuscript for the introduction to the 3rd edition of "The Book of Stainless Steels", now being prepared. The author, through years of contact with the corrosion problems of an important chemical firm, is eminently qualified to discuss this important subject.

Three of the Eight Forms of Corrosion

CORROSION can be classified by the eight forms in which it manifests itself, the basis for this classification being the appearance of the corroded metal. Each form can be identified by mere visual observation. In most cases the naked eye is sufficient, but sometimes magnification is helpful or required. Valuable information for the solution of a corrosion problem can often be obtained through careful observation of the corroded test specimens or failed equipment.

Some of these eight forms are unique and distinct, but all of them are more or less interrelated. This classification is arbitrary, but it covers practically all corrosion failures and problems. The eight forms of corrosion are as follows, a listing not in any particular order:

1. Uniform attack or general corrosion
2. Intergranular corrosion
3. Pitting
4. Dezincification
5. Erosion-corrosion
6. Galvanic or two-metal corrosion
7. Stress-corrosion
8. Concentration cell corrosion.

1. **Uniform Attack** is the most common. It is normally characterized by chemical or electrochemical reaction which proceeds uniformly over the entire exposed surface. The metal becomes thinner and eventually fails. For example, a piece of steel or zinc immersed in dilute sulphuric acid will normally dissolve at a uniform rate over its entire surface. A sheet iron roof will show essentially the same degree of rusting over its outside surface. In liquids this form of corrosion involves simple solution of the metal.

Uniform attack or general over-all corrosion represents the greatest destruction of metal on a tonnage basis. This form of corrosion, however, is not of too great concern from the technical standpoint, because the life of equipment can be accurately estimated on the basis of comparatively simple tests. Merely immersing specimens in the fluid involved is often sufficient. The usual solution to this problem involves the choice of more suitable materials, inhibitors, or protective coatings, or combinations of these expedients. Most of the other forms of corrosion are insidious in nature, and they are considerably more difficult to predict. They are the forms that cause unexpected or premature failures and consequent headaches for the plants or owners of the metallic structures, machines or tools.

2. **Intergranular Corrosion** consists of selective or localized attack at the boundaries of the metallic crystals. Sometimes whole grains are loosened and fall away. Complete disintegration of the metal may result even though a relatively small portion of it "corrodes" on a weight-loss basis. The 18-8 chromium-nickel stainless steels are particularly susceptible to intergranular corrosion when they are not properly heat treated or other-

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wise "stabilized". If plain 18-8 is subjected to a temperature in the range 900 to 1400° F. for an appreciable time, this alloy becomes susceptible to intergranular attack by many corrosives. The commonly accepted explanation is, briefly, that chromium carbides precipitate in the grain boundaries of the metal, and this precipitation "ties up" some of the chromium and depletes or lowers the chromium content of the alloy in the areas adjacent to these carbides, and thus decreases the effective corrosion resistance of the grain boundary material. This is one reason why the carbon content of 18-8 is kept low (below 0.08% in Type 304 stainless steel) for optimum corrosion resistance — that is, there is less carbon to form carbides. These effects can be minimized or practically eliminated by stabilizing the alloy by the addition of either columbium (as is contained in Type 347 stainless) or titanium (Type 321). These elements rather than chromium combine with the carbon and thus depletion of chromium is avoided. If 18-8 steel has been heated in the precipitation range, the corrosion resistance can be restored by heating to a high temperature (1850 to 2050° F.), which puts the carbides back into solution, and cooling rapidly, which retains the carbides in the solid solution (austenite).

The so-called weld decay zone in 18-8 steels is the result of carbide precipitation followed by intergranular corrosion. Figure 1 shows intergranular corrosion in 18-8 as a result of welding and subsequent exposure to a corrosive environment. The localized corrosion in the plate of plain 18-8 in the zone just to the right of the weld is readily apparent. The plate material to the *left* of the weld is a quite similar alloy plus about 0.5% titanium. The absence of localized corrosion in the weld zone of 18-8 Ti is evident.

Figure 2 is an excellent example of intergranular corrosion. This photograph shows a high-alloy stainless casting at approximately actual size after nine months of service in a tank for pickling steel. This casting was not heat treated. High-alloy castings contain very large grains when cast in thick sections, as Fig. 2 shows. The smaller grain size shown along the bottom of the photograph is due to chilling and rapid solidification because of contact with the sand mold.

Intergranular corrosion is by no means confined to stainless steels and alloys. Figure 3 shows nickel shrouding after several years of service in a high-temperature steam turbine in a chemical plant. Nickel is normally a ductile material, but this material became brittle as a result of intergranular attack. Figure 3*a* shows the complete

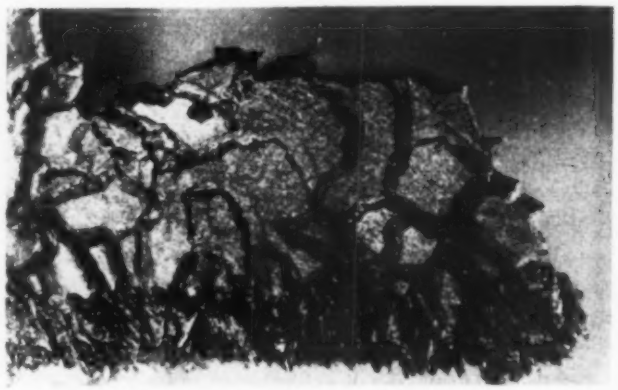


Fig. 2 — Coarse Grains in High-Alloy Stainless Casting Revealed After 9 Months in Pickling Acid. Smaller crystals at lower surface were due to more rapid solidification alongside mold sand

cross section of the shrouding as removed from the turbine. The holes or pits on the surface and edges are due to the complete loss of actual grains of metal, either during service or during polishing in the preparation of the specimen for photographing. Figure 3*b* at 500 diameters indicates the complete envelopment of grains by the intergranular corrosion products. Figure 3*c* is similar to 3*a*, except that the material was heated in hydrogen at 1475° F. for 2 hr. The absence of the network indicates that the grain boundary material was nickel oxide which was reduced by the hydrogen treatment. Figure 3*d* shows grain boundaries at 2000 diameters after hydrogen treatment; the intergranular constituent was not completely reduced.

Nickel shrouding is used successfully in many high-temperature

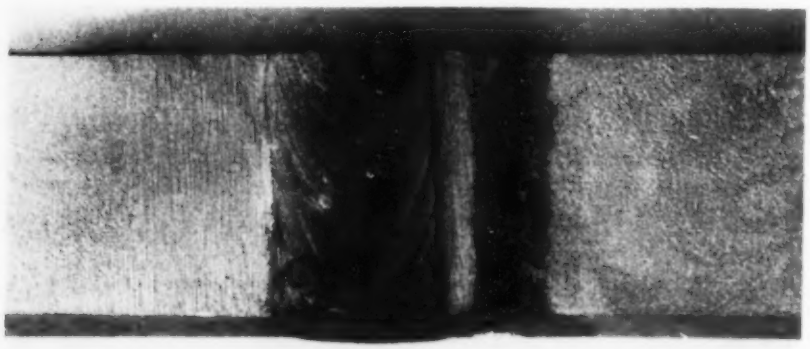
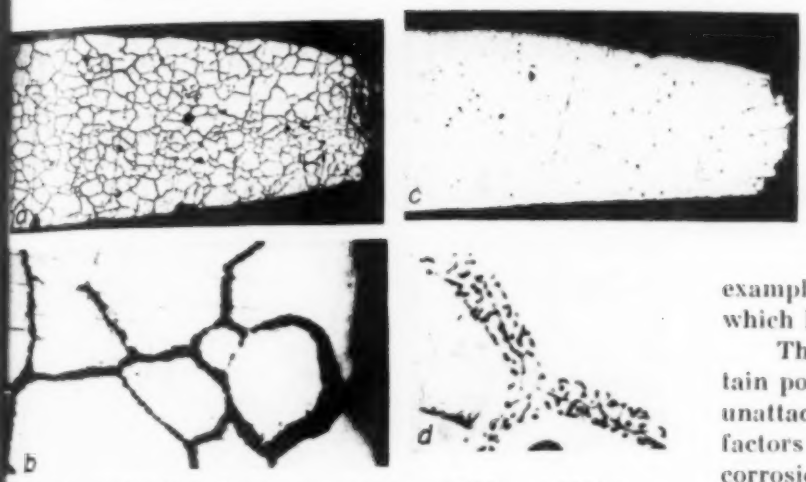


Fig. 1 — Weld in 5/8-In. Stainless Steel Plates After Pickling in Corrosive Solution. About 2/3 size. Note "weld decay" alongside weld in plain 18-8 at right; no corrosion in 18-8 plus 0.50% titanium at left

(a) — As removed; 50 × (c) — After heating in hydrogen; 50 ×



(b) and (d) — Grain boundaries at 500 and 2000 ×

Fig. 3 — Nickel Shrouding Embrittled in High-Temperature Steam Service. All views unetched

steam turbines, but in this machine its performance was unsatisfactory.

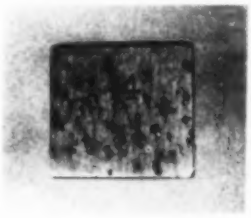
3. **Pitting** is perhaps the most destructive and insidious form of corrosion; containers fail because of perforation, yet only a small amount of metal is lost in the entire structure. In addition, pitting is difficult to evaluate on an experimental basis, and the service life of equipment is correspondingly uncertain. Pitting is probably responsible for more unexpected plant equipment failures than any one of the other seven forms of corrosion.

Pitting is readily recognized. Frequently, most of the surface of the metal shows practically no attack, but the corrosion is localized in more or less isolated areas. For these reasons pitting can be considered as an intermediate situation — something between general over-all corrosion and immunity from attack. For example, a plate of 18% chromium, 8% nickel stainless steel exposed to stagnant sea water may appear to be in perfect condition, but close examination will show the presence of tiny holes that look as though they had been drilled.

In stainless, higher alloy content is no cure. For example, Fig. 4 shows a test specimen of a high alloy (30% nickel plus chromium) after exposure to an aqueous solution of sulphuric acid and sodium chloride containing iron and copper ions. Small holes or pits are readily apparent.

In general, chlorides and other halogens are the chief pitting agents, particularly for stainless steels and chromium-nickel alloys. Ferric chloride is a particularly bad actor. In fact, few, if any, of the commercial alloys of any type available today are suitable for handling mixtures of appreciable concentrations of ferric chloride and hydrochloric acid. However, such active reagents are not always necessary for pitting. For example, Fig. 5 shows pitting on a copper pipe which handled domestic fresh water.

Fig. 4 — Pitting in Thin Specimen of High Chromium-Nickel Alloy (30%) in Solution of $H_2SO_4 + NaCl + Fe''' + Cu''$



The reasons why pitting occurs at a certain point and leaves adjacent areas relatively unattacked are somewhat obscure, but several factors could contribute. Apparently, localized corrosion occurs because of a lack of *complete* homogeneity in the metal surface. The presence of impurities, such as inclusions, or rough spots, scratches, or nicks in the metal surface, could promote the formation of pits. Pits often form under deposits *on* the metal, foreign materials resulting from corrosion products or precipitation from the environment. If the "passive film" on corrosion resistant metals and alloys is broken, this crack would be a potential pit former. Unfortunately, after pitting is started, it tends to progress at an accelerated rate.

Determinations of weight loss are of practically no value when studying pitting. Penetration should be determined by direct measurement with a focusing microscope, or by removing metal mechanically until the pit disappears. In general, vagaries of pitting make it almost imperative to avoid the use of materials in permanent construction, if that material will pit during corrosion tests.

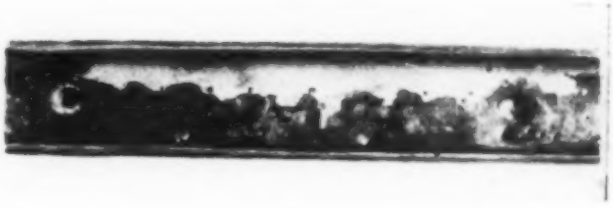


Fig. 5 — Example of Pitting in a Copper Pipe Handling Nothing More Corrosive Than Potable Water

(A discussion of the other five types of corrosion, and a general summary, will be printed in a continuation of this article.)

Isotopes Available for Research

Radioactive Isotopes

WELL OVER 2000 shipments of radioisotopes have been made to nearly 300 institutions throughout the world since the distribution was authorized by the Atomic Energy Commission in August 1946. These comprise over 100 varieties of about 60 elements; 20 of those most important for scientific research are available for accredited foreign institutions. All of them can be produced in minute quantities by cyclotrons, but the byproducts of the uranium chain reacting pile at the Clinton National Laboratory at Oak Ridge, Tenn., make them available in enormously greater quantity and at a small fraction of the cost. For example, one millicurie of C^{14} would cost about $1,000,000 if made by a cyclotron, and about $50 from the chain reacting pile.

Shipments of radioactive isotopes are made in containers adapted to the material and its quantity, and go by air and rail express under arrangements for expedited handling. Radiation leaking from these containers is less than that given off from the fluorescent numerals on a wrist watch. Recipients generally order an appropriate number of badges (such as are worn by employees of the Commission) containing especially sensitive photographic film which totalizes the amount of radiation to which the bearer has been exposed.

Requests for radioisotopes (addressed to Paul C. Aebersold, chief of the Isotopes Division, United States Atomic Energy Commission, Oak Ridge, Tenn.) are reviewed by a committee headed by G. Failla of Columbia University. Allocations are based on the requester's facilities and the nature of the research which is to be instituted. Priority is given to projects of a fundamental nature and to those whose sponsors agree to publicize all records and conclusions. Foreign shipments are made only when the recipient agrees to the latter stipulation without reservation. A list showing the available isotopes, the "standard" quantity in a shipment, and the price is available from the office of the Isotopes Division at Oak Ridge.

Some of the radioisotopes already have been used as important therapeutic agents in the treatment of malignant diseases of the blood and the thyroid gland. Most of the shipments, however, go to research organizations (medical, physical, biological, chemical, agricultural) for use in tracer technique — a field that has hardly yet been touched. Examples of work of interest to the metallurgist are studies of chemical coatings and adsorbed layers on metals, investigations of the earliest stages in oxidation, rusting, and electroplating; of the action of detergents and cleaners; the carburizing and other diffusion phenomena; the composition of minor phases and intermetallic compounds; the properties, thermionic and otherwise, of filaments for tubes and lamps; the homogeneity of powder mixes; the mechanism of precipitation hardening; the partition of sulphur and phosphorus between metal and refining slag.

A further allied use of radiation for tracers in industrial problems is exemplified by the irradiation of steel bearings in the uranium pile for later use in the study of frictional wear.

Stable Isotopes

OVER 100 stable isotopes of 29 elements (normally solid, and not heavier than lead) are now available on loan from a "pool" of the materials obtained from the research and developmental work going on at the Oak Ridge electromagnetic plant (the first to separate U-235 in quantity, early in 1944, for later use in the atomic bomb).

To obtain a stable isotope loan, which is available only to research laboratories in the United States, a request for an allocation must be made to the Isotopes Division, United States Atomic Energy Commission, Oak Ridge, Tenn. Upon approval, the requester must forward his purchase order with $50 for each enriched sample to the Carbide and Carbon Chemicals Corp., Isotopes Office, Oak Ridge, Tenn., the contractor which operates the isotope separation plant. The material will be shipped prepaid. When an investigator has completed his research (or when the date specified in the allocation has expired) the unadulterated isotopic material, whether in the original compound form or in another, must be returned to the Isotopes Office in Oak Ridge, shipment prepaid.

Stable isotopes of the following elements are available from the above source: lithium, boron, carbon, magnesium, silicon, chlorine, potassium, calcium, titanium, chromium, iron, nickel, copper, zinc, germanium, selenium, bromine, zirconium, strontium, molybdenum, silver, cadmium, indium, tin, antimony, tellurium, tungsten, thallium and lead.

A few stable isotopes are more readily concentrated by means other than the electromagnetic process. Of these, H^2, B^{10}, and O^{18} are now obtainable from the Isotopes Division, United States Atomic Energy Commission, Oak Ridge, Tenn.; C^{13} from the Sun Oil Co., Marcus Hook, Pa., and Eastman Kodak Co., Rochester, N. Y.; and N^{15} from Eastman Kodak Co., Rochester, N. Y.

Some important uses of stable isotopes in enriched concentration are for tracers in reactions where the available radioactive isotopes have too short a half-life (such as Mg^{26} rather than Mg^{27} with half-life of 10.2 min.); for tracers in medical and biological studies where radioactivity would interfere with side reactions or other life processes; for raw material for the production of particular radioisotopes (such as radio-iron) which are much more difficult to make and separate otherwise; and for study by physicists of atomic structure, spectral lines, and nuclear transformations.

Tests on 89 large forgings show that best combination of magnetic and physical properties results from a five-stage heat treatment (equalize, anneal, age, low normalize and high temper) giving well agglomerated and dispersed carbides.

Magnetic Properties of Generator Rotors as Affected by Treatment

As has been stated in the opening article last month, there were essentially three types of heat treatments applied to the generator rotor forgings under study. These were *(a)* equalize and anneal; *(b)* equalize, anneal, normalize, and temper; and *(c)* equalize, anneal, double normalize, and temper.

The average tangential yield strengths (at 0.0002 in. per in. extension) and average d.c. magnetization values for the various heat treatments for forgings made from Class B and Class C billets are found in Table I, p. 236. It is apparent that normalize and temper has little advantage over the equalize and anneal, as far as affecting the magnetic properties of Class B billet material, although the 1500° normalize, 1050° temper shows a slight superiority at the higher flux densities. When considering both tensile properties and d.c. magnetization, however, there is a decided advantage in the normalize and temper treatment for Class B billets over the equalize and anneal.

Higher temperings are of advantage, there being a significant difference in magnetic properties between the 1050 and 900° F. tempers.

The double normalizing treatment, with the very high initial normalizing temperature, produces relatively poor magnetic properties in Class B steel. Although there are only two tests on which to judge the 1600° F. normalizing temperature, it would appear advisable to use a lower normalizing temperature, such as 1500° F. This is also desirable because it tends toward a more spheroidized structure (the desirability of which will be discussed later) when followed by tempering treatments.

For forgings made from Class C billet stock, the lower part of Table I shows that with respect to both tensile properties and d.c. magnetization, the normalize-and-temper is definitely superior to the equalize-and-anneal type of heat treatment. This is true whether single or double normalizing is used, and whether relatively low (900° F.) or intermediate (1050° F.) tempering temperatures are used. From the very limited information available and summarized in the last line of the table, there is some benefit to magnetization values of a high tempering temperature (1200° F.). For Class C steel, the improvement in magnetic properties from double normalizing and tempering as compared to single normalizing and tempering is practically nil.

The effect on magnetic properties of cooling rates from the tempering temperature was studied. It was hoped that slow cooling rates would benefit the properties, due to the greater freedom from residual stress. Cooling rates were plotted against the flux density values at 500 amp.-turns per in. for each of the two classes of steel and for each heat treatment concerned. Figure 6 is such a plot

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Table I — Properties in Relation to Heat Treatments

Heat Treatment	Number of Tests	Average Yield Strength*	Average D.C. Magnetization†				
			100	200	300	400	500
		Class B Billets					
Equalize, 1500° anneal	11	36,210	101.1	109.6	114.4	118.2	121.4
1500° normalize, 900° temper	32	47,865	98.1	108.4	114.0	118.0	121.1
1500° normalize, 1050° temper	18	47,400	99.9	109.5	114.9	118.9	121.8
1800 and 1500° normalize, 1200° temper	17	47,080	99.0	108.2	113.5	117.4	120.4
1600° normalize, 1200° temper	2	45,350	99.9	108.7	113.6	117.9	120.5
		Class C Billets					
Equalize, 1500° anneal	6	46,000	96.5	105.9	111.4	115.1	118.4
1500° normalize, 900° temper	13	51,550	96.8	107.6	113.2	117.2	120.4
1500° normalize, 1050° temper	8	50,880	97.4	107.9	113.2	117.1	120.0
1850 and 1500° normalize, 1050° temper	3	55,030	96.2	107.4	113.0	117.3	120.2
1850 and 1500° normalize, 1050 and 1220° temper	2	47,450	99.7	108.5	113.8	117.5	120.8

*Specified yield strength is 35,000 psi. min. at 0.0002 in. per in. extension.
†Kilolines per sq.in. at respective amp.-turns per in.

for the combination of 1500° F. normalize and 900° F. temper, typical of all the patterns obtained. There appears to be no direct correlation between these cooling rates and magnetic properties for these two types of carbon steels. It is possible that a cooling rate effect does exist, but if so, it must be small, at least for the range of cooling rates covered in this study (min. 10° F. per hr.; max. 100° F. per hr.).

Physical Versus Magnetic Properties

It was found that the mechanical properties all showed correlation with the magnetic tests, the yield strength and tensile strength varying inversely, the elongation and reduction of area directly. The ratio of yield to tensile strength was also studied but no correlation could be found with magnetic properties. Yield strength is of greatest importance to the design engineer, and the tangential yield strength was correlated because the tensile test bar is taken from the same location as the magnetic test bar (Fig. 1).

Figure 7 shows this relationship. Correlation is reasonably good, with high yield strength being associated with poor magnetic properties and, conversely, lower yield strength with better d.c. magnetization. Figure 8 demonstrates that this correlation exists for the other types of heat treatment as well, although slopes of the curves are not the same. Equalize and anneal gives the poorest combination of magnetic and physical properties, although the double normalizing treatment gives the poorest d.c. magnetization values for this type of steel (Class B billets) with no improvement in physical properties over those obtained with the single normalizing treatment.

The better magnetic properties found generally associated with low yield strength within a given heat treatment presumably result from two things: First, the greater degree of freedom from internal stress represented by a low yield strength; second, the greater degree of agglomeration of carbides resulting from the higher tempering temperatures responsible for low yield. (The effect of agglomeration of carbides is further discussed under microstructure.)

In the equalize and anneal treatments the magnetic improvement with lowered yield strength presumably is caused by the high degree of freedom from internal stress of an annealed steel. Forgings treated by normalizing and tempering have improved magnetic properties with low yield strengths, possibly due to the agglomerated structure produced by tempering as well as the freedom from internal stress. In the lower part of Table I (forgings from Class C billets) the normalized and tempered forgings may be compared with the equalized and annealed; the agglomerated structure associated with the normalized group has netted a greater benefit to the magnetic properties than the greater degree of freedom from internal stress associated with the annealed group.

The upper part of Table I (forgings from Class B billets) shows by the same comparison that with this lower carbon billet material the effect of agglomeration is less pronounced when compared with the freedom from internal stress of the annealed steel, and that the magnetic properties of the two groups are about the same. However, equalizing and annealing produced yield strengths so low that many of the forgings failed

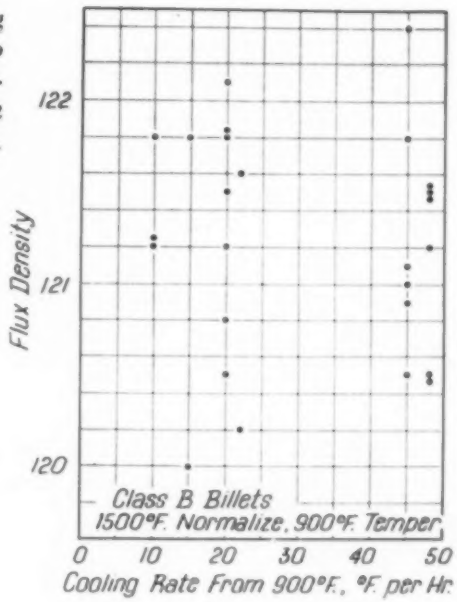


Fig. 6 — Plot Showing That Cooling Rate From Tempering Heat Has no Consistent Effect on D.C. Magnetization of Class B Forgings — at Least Rates Around 15 and 45° F. per Hr.

to meet the specification minimum of 35,000 psi. From these data it is obvious that the better combination of physical and magnetic properties can be obtained by normalizing.

The spread of the data in Fig. 7 and 8 (and Fig. 3) may possibly be caused by other large variables which could not be taken into consideration in plotting the curves, such as the variation in carbon content from forging to forging within a given group; variation in inherent equipment characteristics where different furnaces are used for the same treatment but on different forgings; and unknown changes in mill practice.

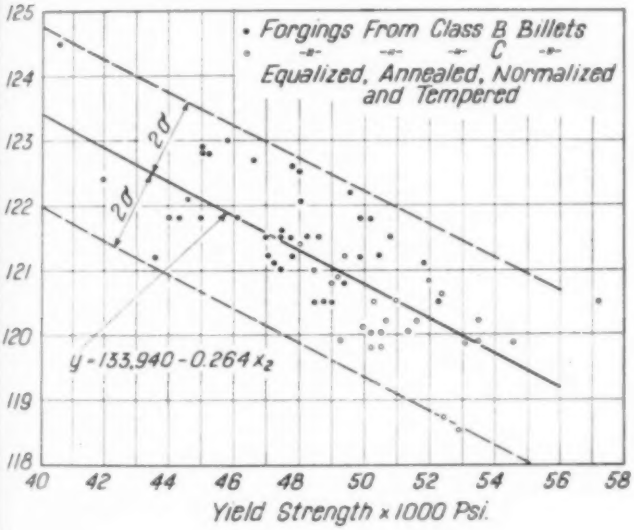


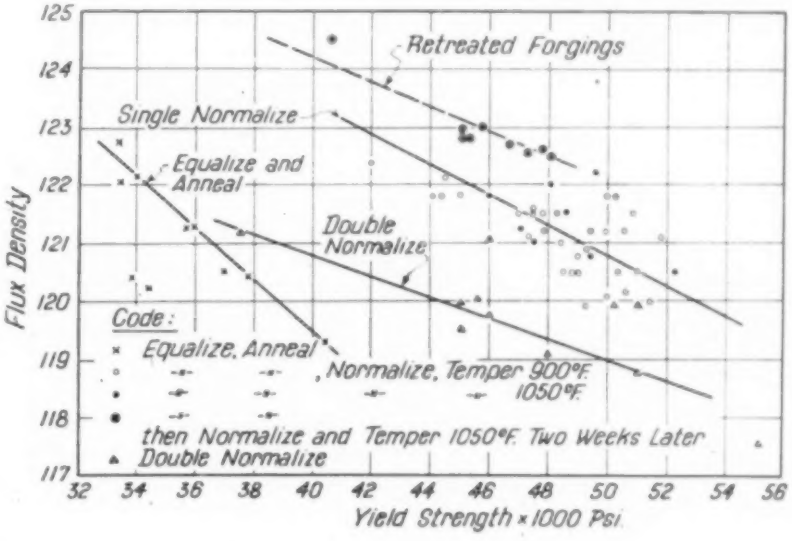
Fig. 7 — Yield Strength Versus D.C. Magnetization (Kilolines per Sq. In. at 500 Amp.-Turns per In.) for the Four-Stage Heat Treatment. Central line represents the average value as determined by the method of least squares

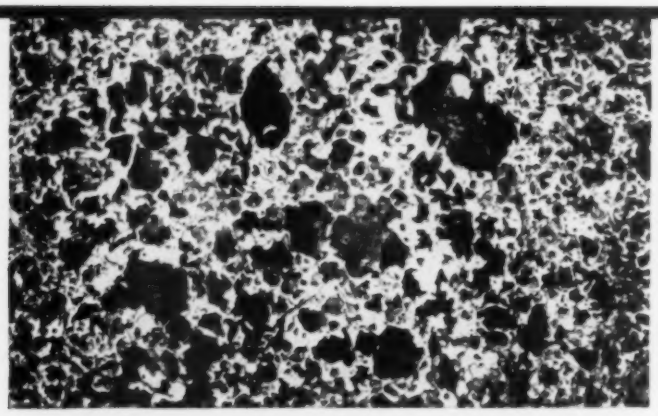
Effect of Retreatments

In Fig. 8 are segregated some data on a certain group of forgings made from Class B billets. Because of poor tensile properties or poor magnetic properties, or both, after equalizing and annealing these forgings had to be given an additional double treatment — normalizing at 1500° F. and tempering at 1050° F. There was a time interval of about two weeks between the original and the retreatment.

Retreatment improved considerably both the tensile and magnetic properties, resulting in the best combination of properties received from any individual group in this investigation. This is shown in the dotted line at the top right of the graph, drawn to represent average conditions for these retreated forgings only. Another group of similar forgings was given the same heat treatment consisting of an equalize, anneal, 1500° F. normalize, and 1050° F. temper, but with no time interval between the anneal and normalize. Results on these forgings are plotted as small black circles. The resulting magnetic properties were definitely inferior to those obtained from the retreated group; the average line computed for them is in about the same position as the line marked "Single Normalize". Naturally, the question arises whether this time

Fig. 8 (below) — Yield Versus D.C. Magnetization, Class B Billets Subjected to Four Heat Treatments





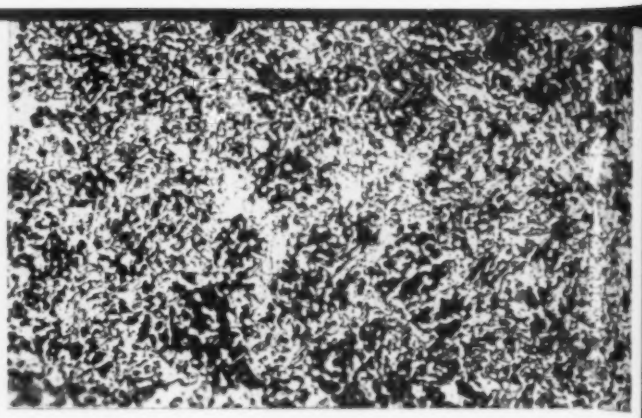


Fig. 9 — Coarse Lamellar Pearlite (at 100 and 1500×) Indicative of Poor Magnetic Properties

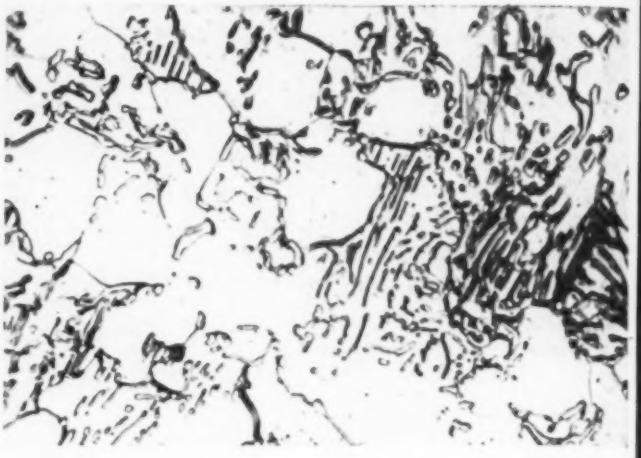


Fig. 10 — Beginning of Speroidization and Carbide Dispersion, Associated With Considerably Reduced M.M.F.

interval between the anneal and normalize had anything to do with the improved magnetic properties, or whether it was merely a coincidence. Only nine forgings needed this retreatment and this is not enough to form the basis of a sound answer. An attempt will be made in the near future to obtain an answer to this question.

Influence of Microstructure

Microstructure has been studied of numerous specimens of the types of steel concerned — usually on forgings with poor magnetic properties. Four were chosen for presentation here. They are shown in Fig. 9 to 12, and their magnetic properties are listed in Table II. The eight photomicrographs shown (made by R. F. Bailey of the Thomson Laboratory) were chosen with certain specific points in mind which will be brought out as the figures are individually discussed.

Figure 9 shows the typical structure associated with poor magnetic properties. Although there are occasional exceptions, usually the coarse-grained lamellar pearlite is indicative of poor or below-average d.c. magnetization values.

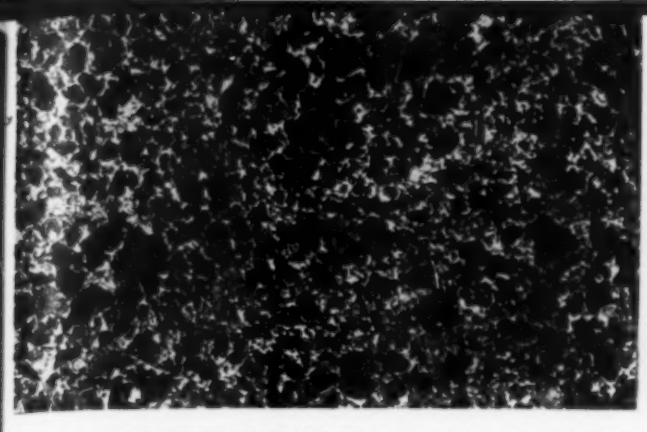
Figure 10 shows the structure usually obtained with better magnetic properties. However, it is not the ideal structure for maximum magnetization values, which is considered to be well spheroidized and agglomerated carbides evenly dispersed throughout the matrix, a conception earlier postulated by W. E. Ruder of General Electric's research laboratory. With these carbon-vanadium steels the predominating factor is believed to be this carbide form and distribution, yet it should be kept in mind that solid solution of the alloying elements in the ferrite is also an important consideration with alloy steels.

So, although Fig. 10 is not considered to have the ideal structure, it is still far superior to the structure in Fig. 9. In most areas, the lamellar pearlite has been broken up, although some laminations still remain. Spheroidization has begun, as well as dispersion of the carbides through the matrix. The difference in flux density (at 500

Table II — Magnetization Values* for Various Microstructures

Micro-structure	Average D.C. Magnetization at				
	100†	200†	300†	400†	500†
Fig. 9	95.0	104.4	109.8	114.0	117.1
Fig. 10	98.6	109.1	114.2	118.2	121.1
Fig. 11	94.5	103.8	108.4	112.2	115.1
Fig. 12	98.2	106.2	111.3	115.0	118.2

*In kilolines per sq.in.
†Amp.-turns per in.



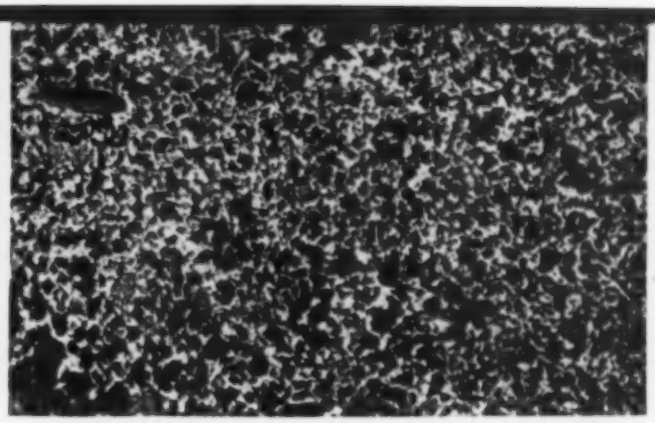


Fig. 11 — Coarse Lamellar Pearlite After Equalizing and Annealing. Poor magnetically. 100 and 1500×

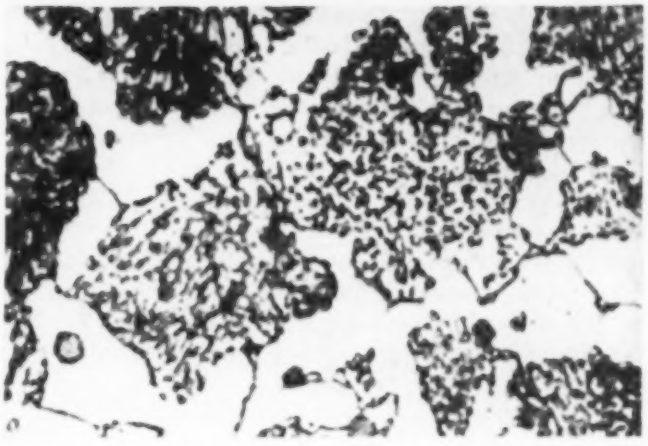


Fig. 12 — Same Forging as Fig. 11 After Additional Double Normalizing and Tempering. Better magnetically

amp.-turns per in.) of the poor structure in Fig. 9 and the good structure in Fig. 10 is 4000 lines per sq.in., or about 3.4%. This difference means that the poorer forging requires about 30% more m.m.f. at a given flux density than the better one!

Figures 11 and 12 show the structures of one forging after two different heat treatments. After the equalize and anneal, the structure as shown in Fig. 11 contains the typical coarse lamellar pearlite, the d.c. magnetization values being very poor. The double normalizing and tempering which followed considerably improved the magnetic properties, although they were still mediocre. The resulting structure, Fig. 12, shows that the lamellar pearlite has been fairly well broken up, although spheroidization and dispersion of the carbides have not progressed very far. It can be regarded as a transition stage between the poor lamellar and good spheroidized and dispersed structures.

It is the belief of the authors that the influence of carbide form and distribution on magnetic properties is a mechanical effect, in which well-dispersed and agglomerated carbides offer the least resistance to the creation of magnetic lines of force. Conversely, lamellar pearlite presents a series of barriers to the establishment of flux lines. There is the further thought that whereas stress is known to be detrimental to magnetic properties, the minimized internal stress represented by well agglomerated and dispersed carbides may be making its own contribution to improved magnetic properties, in addition to the mechanical effect already noted.

Exceptions to some of these statements have been observed, but in general the microstructures and magnetic properties have the relationships as presented for carbon-vanadium steel.

Amount of Forging

Since all of the forgings in this study were to the same drawing, and since there were differences in the original billet sizes, different forgings must have received varying amounts of hot work. To determine whether this had an effect on magnetic properties, billet diameter was plotted against flux density at 500 amp.-turns per in. No correlation could be found. Billets of 21 in. diameter varied more or less at random in flux density from 119.9 to 122.1 kilolines per sq.in. at 500 amp.-turns per in. 23-in. billets varied from 120.0 to 123.0 with results somewhat concentrated toward the top. 25-in. billets varied at random between 120.5 and 122.2, and one 26-in. billet's flux density was 120.7 kilolines.

If the amount of forging from billet to rotor has any influence on the magnetic properties, it is certainly very small and is well hidden among other larger effects.

Effect of Deoxidation Practice

Mention has been made of the fact that unknown mill practice changes could conceivably constitute a variable contributing to the spread in Fig. 3, 7, and 8. It may be interesting to note that during another investigation on alloy steel rotor forgings a change in deoxidizing practice was uncovered which, on closer examination, gave considerable indication of a strongly detrimental effect on magnetic properties. Specifically, a number of heats deoxidized in the ladle with calcium-silicon-manganese resulted in rotor forgings with poor magnetic properties, whereas standard deoxidizing practice in the furnace with silicon and manganese produced acceptable d.c. magnetization values. The other noticeable effects of the calcium-manganese-silicon deoxidizer were a slight desulphurizing tendency, and higher yield and tensile strengths for a given heat treatment.

Summary and Conclusions

Since the d.c. magnetization, carbon content, and yield strength were found to be interrelated, and since carbon content and yield strength seemed to be the most important factors in considering magnetic properties (yield strength being indicative of the important factor of heat treatment), attempts were unsuccessfully made to establish prediction equations by means of single and multiple regressions.

However, by adding the equations for the average lines of Fig. 3 and 7, as shown on the respective graphs, we have

$$y = 133{,}290 - 13{,}750\,x_1 - 0.132\,x_2$$

where y = flux density in kilolines per sq.in. at 500 amp.-turns per in.

x_1 = % carbon

x_2 = psi. yield strength

This equation will predict only the average d.c. magnetization value for a given carbon content and yield strength. The equation shows mathematically that it is desirable to keep carbon as low as possible, consistent with meeting required yield strength, and that yield strength should be maintained as near as possible to the permitted minimum.

Summarizing, then, several conclusions have been drawn from the investigations:

1. Magnetic quality varies inversely with the carbon content. Statistical methods established that the effect was real.

2. No relationship between the manganese content and flux density could be established over the narrow manganese range encountered.

3. The vanadium content varied within such close limits that its influence could not be studied.

4. Total alloy content, excluding nickel whose effect is neutral, shows an inverse relationship with d.c. magnetization values.

5. An equalize, anneal, normalize, and temper was found to be the heat treatment which produced the best combination of physical and magnetic properties. The normalizing temperature should be kept as low as possible, and the tempering temperature as high as possible, while still maintaining required physical properties. The double normalize, and the equalize and anneal — which were the other treatments involved — are inferior because of their effect on magnetic or physical properties, or both.

6. No effect of the cooling rate on magnetic properties resulting from furnace cooling from the tempering temperatures could be found, at least up to 100° F. per hr. If any influence exists it must be small.

7. A portion of the data indicates that better magnetic properties can be obtained with the equalize, anneal, normalize, and temper heat treatment if there is a time lag between the anneal and normalize. Whether this is real or coincidental is not known, but it warrants further investigation.

8. An inverse relationship was found to exist between flux density and both tensile and yield strengths, whereas a direct relationship exists between flux density and both elongation and reduction of area. These relationships exist for any type of heat treatment although the slopes of the average lines are different.

9. Coarse lamellar pearlite is nearly always associated with poor magnetic properties. Well agglomerated and dispersed carbides generally indicate good magnetic properties. The lamellar structure may present a series of mechanical barriers to the creation of magnetic flux lines. Agglomerated structure offers much less resistance and, being one of minimum internal stress, probably is beneficial to magnetic properties for that additional reason.

10. No relationship could be established between magnetic properties and the amount of reduction in forging from billet to rotor forging.

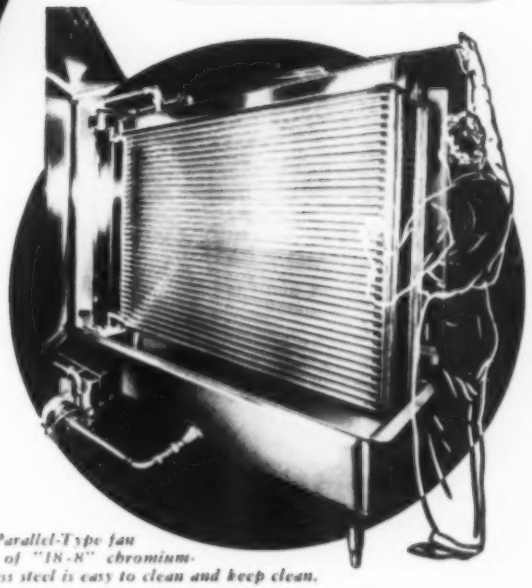
11. Deoxidizing an alloy steel in the ladle with calcium-silicon-manganese is believed to be detrimental to magnetic properties when compared to standard deoxidizing of the same steel in the furnace with silicon and manganese.

12. In general, a better level of magnetic properties for carbon-vanadium forgings should be obtained by using an equalize, anneal, normalize, and temper type of heat treatment, by keeping the carbon content down to the minimum necessary to meet physical properties, by holding residual alloy content to a minimum, and by keeping the yield strength as close to the specified minimum as can be safely done in production heat treating.

When Product Purity is Essential

. . . take a tip from Dairymen

The above 300 gallon Vacuum "A&G" Buttermilk Machine used in a Baltimore, Md. creamery was fabricated from "18-8" chromium-Nickel stainless steel by Jensen Machinery Co., Inc.



This Jensen Parallel-Type fan cooler made of "18-8" chromium-Nickel stainless steel is easy to clean and keep clean.

Even the *least* contamination by bacteria spells D-A-N-G-E-R to processors of milk.

The faintest contamination from products of corrosion may affect the taste.

And that's why chromium Nickel austenitic stainless steel is used for so many pasteurizers, storage tanks, surface coolers, piping and other units for the dairy products industry.

Easy to keep hygienically clean, standard "18-8" stainless is highly resistant to foodstuffs, atmosphere, most organic and a great many inorganic chemicals, and to dyes and sterilizing solutions.

In addition, for many applications in various fields where resistance to corrosion, impact, wear and abrasion are required, "18-8" permits cutting bulk and dead weight without sacrificing strength or durability. Its great resistance to both high and low temperature effects is especially valuable.

Leading steel companies produce stainless steel containing Nickel in sheet, strip, bar and tubular form. A list of the sources of supply will be furnished on request.

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TRADE MARK

Over the years, International Nickel has accumulated a fund of useful information on the selection, fabrication, treatment and performance of engineering alloy steels, stainless steels, cast irons, copper-base and other alloys containing Nickel. This information is yours for the asking. Write for "List A" of available publications.

THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET NEW YORK 5, N. Y.

A.I.S.I. Standard Alloy Steel Compositions

A.I.S.I. List Revised Oct. 30, 1947

Openhearth and Electric Furnace Alloy Steels
(Bars, Billets, Blooms and Slabs)

S.A.E. List Revised October 1947

A.I.S.I. Number *(a)*	C	Mn	P Max.*	S Max.*	Si†	Ni	Cr	Mo	1947 S.A.E. Number
A 1320	0.18-0.23	1.60-1.90	0.040	0.040	0.20-0.35	.....	.....	.....	1320
A 1321	0.17-0.22	1.80-2.10	0.050	0.050	0.20-0.35	.....	.....	.....	....
A 1330	0.28-0.33	1.60-1.90	0.040	0.040	0.20-0.35	.....	.....	.....	1330
A 1335	0.33-0.38	1.60-1.90	0.040	0.040	0.20-0.35	.....	.....	.....	1335
A 1340	0.38-0.43	1.60-1.90	0.040	0.040	0.20-0.35	.....	.....	.....	1340
A 2317	0.15-0.20	0.40-0.60	0.040	0.040	0.20-0.35	3.25-3.75	.....	.....	2317
A 2330	0.28-0.33	0.60-0.80	0.040	0.040	0.20-0.35	3.25-3.75	.....	.....	2330
A 2335	0.33-0.38	0.60-0.80	0.040	0.040	0.20-0.35	3.25-3.75	.....	.....	....
A 2340	0.38-0.43	0.70-0.90	0.040	0.040	0.20-0.35	3.25-3.75	.....	.....	2340
A 2345	0.43-0.48	0.70-0.90	0.040	0.040	0.20-0.35	3.25-3.75	.....	.....	2345
E 2512	0.09-0.14	0.45-0.60‡	0.025	0.025	0.20-0.35	4.75-5.25	.....	.....	2512
A 2515	0.12-0.17	0.40-0.60	0.040	0.040	0.20-0.35	4.75-5.25	.....	.....	2515
E 2517	0.15-0.20	0.45-0.60‡	0.025	0.025	0.20-0.35	4.75-5.25	.....	.....	2517
A 3115	0.13-0.18	0.40-0.60	0.040	0.040	0.20-0.35	1.10-1.40	0.55-0.75	.....	3115
A 3120	0.17-0.22	0.60-0.80	0.040	0.040	0.20-0.35	1.10-1.40	0.55-0.75	.....	3120
A 3130	0.28-0.33	0.60-0.80	0.040	0.040	0.20-0.35	1.10-1.40	0.55-0.75	.....	3130
A 3135	0.33-0.38	0.60-0.80	0.040	0.040	0.20-0.35	1.10-1.40	0.55-0.75	.....	3135
A 3140	0.38-0.43	0.70-0.90	0.040	0.040	0.20-0.35	1.10-1.40	0.55-0.75	.....	3140
A 3141	0.38-0.43	0.70-0.90	0.040	0.040	0.20-0.35	1.10-1.40	0.70-0.90	.....	3141
A 3145	0.43-0.48	0.70-0.90	0.040	0.040	0.20-0.35	1.10-1.40	0.70-0.90	.....	3145
A 3150	0.48-0.53	0.70-0.90	0.040	0.040	0.20-0.35	1.10-1.40	0.70-0.90	.....	3150
E 3310	0.08-0.13	0.45-0.60‡	0.025	0.025	0.20-0.35	3.25-3.75	1.40-1.75	.....	3310
E 3316	0.14-0.19	0.45-0.60‡	0.025	0.025	0.20-0.35	3.25-3.75	1.40-1.75	.....	3316
A 4017	0.15-0.20	0.70-0.90	0.040	0.040	0.20-0.35	.....	.....	0.20-0.30	4017
A 4023	0.20-0.25	0.70-0.90	0.040	0.040	0.20-0.35	.....	.....	0.20-0.30	4023
A 4024	0.20-0.25	0.70-0.90	0.040	*(b)*	0.20-0.35	.....	.....	0.20-0.30	4024
A 4027	0.25-0.30	0.70-0.90	0.040	0.040	0.20-0.35	.....	.....	0.20-0.30	4027
A 4028	0.25-0.30	0.70-0.90	0.040	*(b)*	0.20-0.35	.....	.....	0.20-0.30	4028
A 4032	0.30-0.35	0.70-0.90	0.040	0.040	0.20-0.35	.....	.....	0.20-0.30	4032
A 4037	0.35-0.40	0.70-0.90	0.040	0.040	0.20-0.35	.....	.....	0.20-0.30	4037
A 4042	0.40-0.45	0.70-0.90	0.040	0.040	0.20-0.35	.....	.....	0.20-0.30	4042
A 4047	0.45-0.50	0.70-0.90	0.040	0.040	0.20-0.35	.....	.....	0.20-0.30	4047
A 4053	0.50-0.56	0.75-1.00	0.040	0.040	0.20-0.35	.....	.....	0.20-0.30	4053
A 4063	0.60-0.67	0.75-1.00	0.040	0.040	0.20-0.35	.....	.....	0.20-0.30	4063
A 4068	0.63-0.70	0.75-1.00	0.040	0.040	0.20-0.35	.....	.....	0.20-0.30	4068
(c)	0.17-0.22	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.40-0.60	0.20-0.30	4119
(c)	0.23-0.28	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.40-0.60	0.20-0.30	4125
A 4130	0.28-0.33	0.40-0.60	0.040	0.040	0.20-0.35	.....	0.80-1.10	0.15-0.25	4130
E 4132	0.30-0.35	0.40-0.60	0.025	0.025	0.20-0.35	.....	0.80-1.10	0.18-0.25**	....
E 4135	0.33-0.38	0.70-0.90	0.025	0.025	0.20-0.35	.....	0.80-1.10	0.18-0.25**	....
A 4137	0.35-0.40	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.80-1.10	0.15-0.25	4137
E 4137	0.35-0.40	0.70-0.90	0.025	0.025	0.20-0.35	.....	0.80-1.10	0.18-0.25**	....
A 4140	0.38-0.43	0.75-1.00	0.040	0.040	0.20-0.35	.....	0.80-1.10	0.15-0.25	4140
A 4142	0.40-0.45	0.75-1.00	0.040	0.040	0.20-0.35	.....	0.80-1.10	0.15-0.25	....
A 4145	0.43-0.48	0.75-1.00	0.040	0.040	0.20-0.35	.....	0.80-1.10	0.15-0.25	4145
A 4147	0.45-0.50	0.75-1.00	0.040	0.040	0.20-0.35	.....	0.80-1.10	0.15-0.25	....
A 4150	0.48-0.53	0.75-1.00	0.040	0.040	0.20-0.35	.....	0.80-1.10	0.15-0.25	4150
A 4317	0.15-0.20	0.45-0.65	0.040	0.040	0.20-0.35	1.65-2.00	0.40-0.60	0.20-0.30	4317
A 4320	0.17-0.22	0.45-0.65	0.040	0.040	0.20-0.35	1.65-2.00	0.40-0.60	0.20-0.30	4320
A 4337	0.35-0.40	0.60-0.80	0.040	0.040	0.20-0.35	1.65-2.00	0.70-0.90	0.20-0.30	....
A 4340	0.38-0.43	0.60-0.80	0.040	0.040	0.20-0.35	1.65-2.00	0.70-0.90	0.20-0.30	4340
A 4608	0.06-0.11	0.25-0.45††	0.040	0.040	0.25max.	1.40-1.75	.....	0.15-0.25	4608
A 4615	0.13-0.18	0.45-0.65	0.040	0.040	0.20-0.35	1.65-2.00	.....	0.20-0.30	4615
E 4617	0.15-0.20	0.45-0.65	0.025	0.025	0.20-0.35	1.65-2.00	.....	0.20-0.27‡‡	4617
A 4620	0.17-0.22	0.45-0.65	0.040	0.040	0.20-0.35	1.65-2.00	.....	0.20-0.30	4620
X 4620	0.18-0.23	0.50-0.70	0.040	0.040	0.20-0.35	1.65-2.00	.....	0.20-0.30	X4620
E 4620	0.17-0.22	0.45-0.65	0.025	0.025	0.20-0.35	1.65-2.00	.....	0.20-0.27	....
A 4621	0.18-0.23	0.70-0.90	0.040	0.040	0.20-0.35	1.65-2.00	.....	0.20-0.30	4621
A 4640	0.38-0.43	0.60-0.80	0.040	0.040	0.20-0.35	1.65-2.00	.....	0.20-0.30	4640
E 4640	0.38-0.43	0.60-0.80	0.025	0.025	0.20-0.35	1.65-2.00	.....	0.20-0.27	....
A 4812	0.10-0.15	0.40-0.60	0.040	0.040	0.20-0.35	3.25-3.75	.....	0.20-0.30	4812
A 4815	0.13-0.18	0.40-0.60	0.040	0.040	0.20-0.35	3.25-3.75	.....	0.20-0.30	4815
A 4817	0.15-0.20	0.40-0.60	0.040	0.040	0.20-0.35	3.25-3.75	.....	0.20-0.30	4817
A 4820	0.18-0.23	0.50-0.70	0.040	0.040	0.20-0.35	3.25-3.75	.....	0.20-0.30	4820
A 5045	0.43-0.48	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.55-0.75	.....	5045
A 5046	0.43-0.50	0.75-1.00	0.040	0.040	0.20-0.35	.....	0.20-0.35	.....	5046
(c)	0.13-0.18	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.70-0.90	.....	5115
A 5120	0.17-0.22	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.70-0.90	.....	5120
A 5130	0.28-0.33	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.80-1.10	.....	5130
A 5132	0.30-0.35	0.60-0.80	0.040	0.040	0.20-0.35	.....	0.80-1.05	.....	5132
A 5135	0.33-0.38	0.60-0.80	0.040	0.040	0.20-0.35	.....	0.80-1.05	.....	5135
A 5140	0.38-0.43	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.70-0.90	.....	5140
A 5145	0.43-0.48	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.70-0.90	.....	5145
A 5147	0.45-0.52	0.75-1.00	0.040	0.040	0.20-0.35	.....	0.90-1.20	.....	5147
A 5150	0.48-0.53	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.70-0.90	.....	5150
A 5152	0.48-0.55	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.90-1.20	.....	5152
E50100	0.95-1.10	0.25-0.45	0.025	0.025	0.20-0.35	.....	0.40-0.60	.....	50100
E51100	0.95-1.10	0.25-0.45	0.025	0.025	0.20-0.35	.....	0.90-1.15	.....	51100
E52100	0.95-1.10	0.25-0.45	0.025	0.025	0.20-0.35	.....	1.30-1.60	.....	52100
A 6120	0.17-0.22	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.70-0.90	0.10min.V	....
A 6145	0.43-0.48	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.80-1.10	0.15min.V	....
A 6150	0.48-0.53	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.80-1.10	0.15min.V	6150
A 6152	0.48-0.55	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.80-1.10	0.10min.V	....

A8615 to A8660; A8719 to A8750; A9255 to A9262, See *Metal Progress* Data Sheet No. 17

E 9310	0.08-0.13	0.45-0.65	0.025	0.025	0.20-0.35	3.00-3.50	1.00-1.40	0.08-0.15	9310
E 9315	0.13-0.18	0.45-0.65	0.025	0.025	0.20-0.35	3.00-3.50	1.00-1.40	0.08-0.15	9315
E 9317	0.15-0.20	0.45-0.65	0.025	0.025	0.20-0.35	3.00-3.50	1.00-1.40	0.08-0.15	9317

A9437 to A9445; A9747 and A9763; A9840 to A9850, See *Metal Progress* Data Sheet No. 17

*Phosphorus and sulphur limitations for each process are as follows: Basic electric, 0.025 max.; basic openhearth, 0.04 max.; acid electric, 0.05 max.; and acid openhearth, 0.05 max.

†Lowest silicon limit for acid openhearth and acid electric is 0.15%.

‡For openhearth steel the manganese is 0.40 to 0.60.

**For openhearth steel the molybdenum is 0.15 to 0.25.

††S.A.E. specification reads "0.45% max."

‡‡For openhearth steel the molybdenum is 0.20 to 0.30.

NOTES: *(a)* Prefix A means basic openhearth alloy steel; E means electric furnace steel.

(b) Sulphur range: 0.035 to 0.050%.

(c) Eliminated from A.I.S.I. Standards, as revised October 30, 1947.

In practice it is found that erratic results and shallow cases are likely to result when inert nitrogen is used as a carrier gas for the methane or other hydrocarbon. Laboratory tests indicate that extremely minute amounts of H_2O and CO_2 upset the furnace atmosphere equilibrium, and that a moderate amount of CO and H_2 are required to offset this condition.

Nitrogen as a Carrier Gas in Gas Carburizing

MUCH THOUGHT has been given to the use of nitrogen as a carrier gas in gas carburizing, for dry nitrogen is a nonflammable, nontoxic gas which is neither carburizing nor decarburizing to steel at heat treating temperatures. In addition, with wartime advances in extracting oxygen from air, byproduct nitrogen has become readily available at comparatively low cost. In order to appraise the possibilities and limitations of this application in commercial gas carburizing, carburizing atmospheres should be evaluated from the standpoint of equilibrium and flow, both when using nitrogen and the more common carrier gases, and test data on carburizing runs should be analyzed and discussed. Finally, the equilibrium percentages of the various constituents of the furnace atmosphere should be known, the significance of the dew point appraised, and problems arising in commercial operation considered.

Functions of a Carrier Gas

The carrier gas has three separate functions: *(a)* To purge the furnace and vestibules; *(b)* to provide positive pressure in the carburizing chamber; and *(c)* to dilute active hydrocarbon gases enough to prevent soot deposit on work and furnace interior. Each must be given attention.

Purging consists of displacing air or contaminated atmosphere in the furnace and vestibules with the carrier gas. This is one of the most important functions of a carrier gas, as small amounts of oxygen infiltrating into the furnace will react with the hydrocarbon gases to form CO_2 and H_2O which are deleterious to the carburizing process. As shown in Fig. 1, continuous furnaces have both charge and discharge vestibules *A* and *B* which require flushing during each cycle.

Once properly purged, a positive gas pressure must be maintained inside the furnace. The flow of carrier gas required for purging of vestibules in a continuous furnace will generally be sufficient to prevent any air infiltration between operating cycles. This flow having been determined, a controlled volume of hydrocarbon gas is added to the carrier gas to supply adequate carbon for the steel loaded into the furnace.

Typical Carrier Gases — The most common carrier gas used today is catalytic generator gas, produced by the pyrolysis of a controlled mixture of air and hydrocarbon gas in an externally heated

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retort in the presence of a catalyst, and quickly cooled. Figure 2 shows a battery of Holcroft catalytic gas generators for producing this type of gas.

A typical catalytic generator gas will analyze as follows:

CO_2	0.1 to 0.3%
CO	20.0%
CH_4	0.6%
H_2	40.0%
H_2O	0.22 to 0.35% (dew point +10 to +20° F.)
N_2	Balance (40%±)

This analysis falls between American Gas Assoc.'s Class 301 and Class 302. The CO and H_2 percentage will vary with the type of hydrocarbon gas used. Commercial practice has proven that it is not necessary to operate this type of generator at zero CO_2 and dew points below zero Fahrenheit; such extreme conditions lower the capacity of the generator and invite generator troubles.

Another type of generator gas commonly used is considerably higher in nitrogen. It is prepared by bringing some flue gas or other product of combustion (from which most of the water vapor has been removed) into contact with a hot carbonaceous substance in an externally heated retort, either with or without a catalytic material. The gas composition will vary with the method of preparation but will be within the range below, which represents two extreme conditions found in commercial operation:

CO_2	0.0 to 0.3%
CO	16.0 to 20.0%
CH_4	0.0 to 1.0%
H_2	2.0 to 25.0%
H_2O	0.03 to 0.35% (dew point −30 to +20° F.)
N_2	Balance (70%±)

Characteristics of a Carburizing Atmosphere

In order to observe the effects of a given carrier gas, it is necessary to study the characteristics of the furnace atmosphere since the latter will vary from that of the generator gas, due to the difference in generator and furnace operating temperatures and to the reactions of the generator gas with the added hydrocarbon gas and the stock being carburized. In making such a study, there are two basic considerations: *(a)* equilibrium conditions for the component gases and *(b)* carbon available for the carburizing reaction.

For every heat treating temperature there are equilibrium conditions for the furnace atmosphere which are determined by the following well-known reactions:

$$2CO \rightleftarrows CO_2 + C \qquad K = \frac{(CO)^2}{(CO_2)} \qquad (1)$$

$$H_2O + CO \rightleftarrows H_2 + CO_2 \qquad K = \frac{(CO) \times (H_2O)}{(CO_2) \times (H_2)} \qquad (2)$$

The equilibrium constant, K, increases with increasing temperature in each reaction.

Reaction (1) is between solid carbon, C, and the gases CO and CO_2. For example, at 1650° F. the saturated austenite value for a plain carbon steel is 1.20% carbon, as shown by the iron-carbon equilibrium diagram. The activity of this percentage of carbon at this temperature may be considered as unity — 100% — and the figure for activity decreases with carbon concentration. Thus, assuming a straightline relationship, a 0.60% carbon steel would have an activity of 0.5 or 50% at 1650° F. The result is that as the percentage of carbon at the surface of the steel is less and less than that of

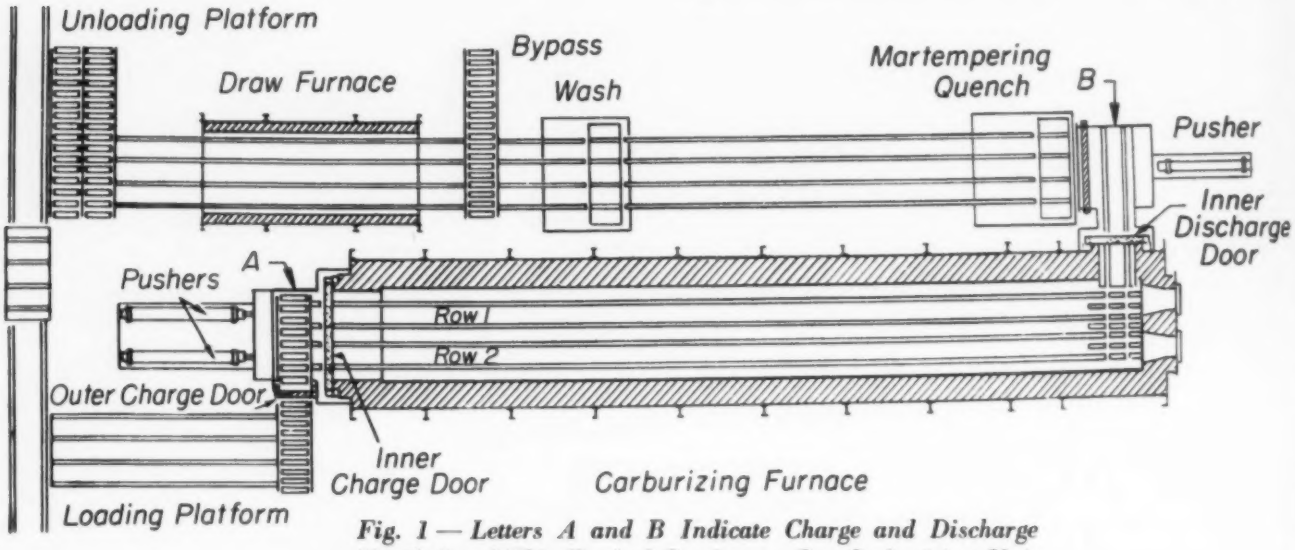


Fig. 1 — Letters A and B Indicate Charge and Discharge Vestibules of This Typical Continuous Gas Carburizing Unit

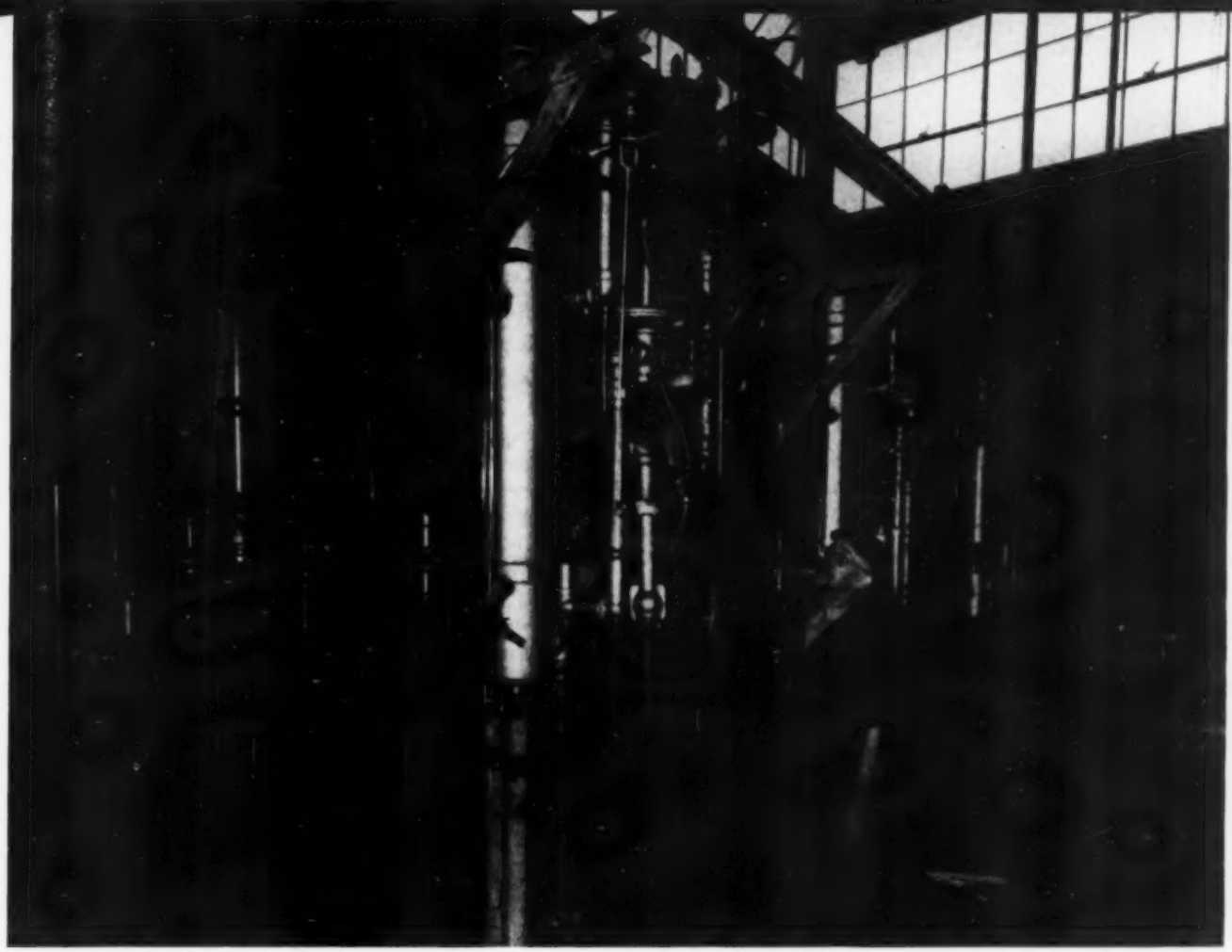


Fig. 2 — Typical Battery of Three Catalytic Gas Generators

saturated austenite at a given temperature, the allowable CO_2 in the gas at equilibrium with that surface increases. In other words, a hypereutectoid case requires a gas very low in CO_2; if the surface carbon on the completed work need be no higher than, say, 0.90%, the carburizing gas need not be so highly purified of CO_2.

Reaction (2) is the water-gas reaction and determines the equilibrium percentages of CO_2, H_2, CO and H_2O in the furnace atmosphere. For example, if water vapor (steam) were added to a given furnace atmosphere, reaction (2) would go to the right, increasing the CO_2 content of the gas until equilibrium was again attained.

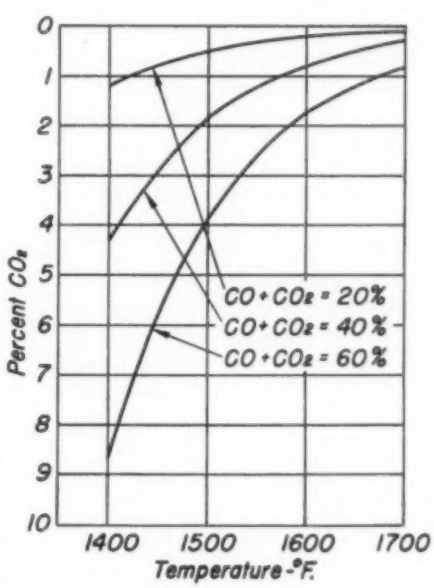


Fig. 3 — Amount of CO_2 Allowable for CO:CO_2 Equilibrium at Various Temperatures (Gas at 1 Atm.)

Calculating for a furnace atmosphere containing 20% CO and 40% H_2 at 1700° F., it is found that the equilibrium analysis* of this gas is 0.09% CO_2, 20.0% CO, 40% H_2, 0.24% H_2O (or a dew point of +11° F.) and about 40% N_2.

If the furnace temperature were reduced to 1500° F. the CO:CO_2 equilibrium would change according to reaction (1) until the equilibrium value of 0.5% CO_2 was reached. The H_2O content, equation (2), also would increase to its equilibrium value, namely 0.9%.†

As to the second basic consideration named above, the carbon available for the carburizing reaction is obtained from the breakdown of hydrocarbon gas added to the carrier in controlled amount. The quantity added at the furnace is a function of the surface area of the load and the carburizing time. A

*K = 46.24 for reaction (1) at 1700° F.
K = 1.343 for reaction (2) at 1700° F.
†K = 8.147 for reaction (1) at 1500° F.
K = 0.9398 for reaction (2) at 1500° F.

Table I — Summary of Gas Conditions

Carburizing at 1700° F. in 0.2-cu.ft. retort. Atmosphere in furnace at 0.5 in. water pressure

Run No.	Time at Heat	Total Case Depth	Gas Flow (Cu.Ft. per Hr.)			Furnace Atmosphere (Outlet Gas)					Surface Carbon	Carbon Released Lb. per Hr.
			Generator Gas	Nitrogen	Natural Gas	CO_2*	CO	CH_4	H_2	Dew Point		
1	4 hr.	0.051 in.	28	—	1.1	0.0	16.7	3.6	44.7	+12° F.	1.35%	0.018
2	4	0.048	—	28	2.2	0.0	0.9	3.5	10.5	−36	1.26	0.038
3	3	0.035	—	38	2.2	0.0	0.7	3.6	5.4	−30	1.19	0.025
4	3	0.031	—	55	2.2	0.0	0.6	2.5	4.3	−29	1.08	0.025
5	4	0.036	—	38	1.6	0.0	0.7	2.7	4.1	−23	1.12	0.017

*The quantity of CO_2 present was too small to measure.

method for determining the amount of carbon released for carburizing is explained in a subsequent calculation.

Equilibrium Characteristics of a Carrier Gas

Carrier gases may be compared by calculating the CO_2 equilibrium content at 1700° F. As previously mentioned, the CO_2 equilibrium value of a gas with 20% CO and 40% H_2 is approximately 0.09% at 1700° F.

When nitrogen is used as a carrier gas instead of a generator gas high in CO, the resulting atmosphere in the furnace will probably contain less than 1% CO (assuming it is formed from the small amounts of oxygen present in commercial nitrogen). Figure 3 shows that as the total of carbon oxides decreases, less and less CO_2 is allowable for equilibrium. Thus, for a furnace atmosphere containing only 1% CO, the allowable CO_2 content would be in the neighborhood of 0.0002%; any higher amount than this mere trace would lose its oxygen to its surroundings — perhaps to some oxidizable components of the gas, but conceivably even to the steel in which it might be in contact, decarburizing the surface. Since hydrogen, formed by the breakdown of hydrocarbons added to supply carbon for carburizing, is present in small amounts, the water vapor content of this furnace atmosphere must also be much lower, in order to have an atmosphere gas of the same carburizing strength as that produced by a generator gas high in CO.

These considerations give the theoretical reasons why a carrier gas quite high in nitrogen has not been too successful in heat treatment practice, despite the inert nature of nitrogen itself. The slightest contamination of a 100% nitrogen gas atmosphere with oxygen in any form — for example, a leak that allows air to enter, some moisture in the gas or absorbed from the furnace brickwork, or a little scale on the metal parts — may cause serious decarburization in the steel, yet the CO_2 present may be so small as to be unmeasurable by ordinary analysis. A moderate CO content is therefore desirable in a carrier gas, so it may tolerate minor amounts of CO_2 at carburizing temperature.

Laboratory Tests

Further comparison of the effect of different carrier gases may be made by examining results of a series of five tests made at Holcroft & Co.'s laboratory, and by computing the carbon available for carburizing, using the amount of methane in inlet and exhaust gases respectively.† These were run in a vertical retort furnace (8 in. diameter by 7 in. high) at 1700° F. Catalytic generator gas, commercial nitrogen and Detroit city gas (natural gas) were used in varying amounts. S.A.E. 1020 bars were run for determining carbon concentration and case depth. Table I summarizes the atmospheres used.

†The carbon available for carburizing at 1700° F. is released according to the equation: $CH_4 = C + 2H_2$. We calculate Detroit city gas as 100% methane.

For run No. 1

28 cu.ft. per hr. generator gas containing 1.8% methane = 0.5 cu.ft. per hr. methane

1.1 cu.ft. per hr. natural gas added = 1.1 cu.ft. per hr. methane

29.1 cu.ft. per hr. total inlet gas content 1.6 cu.ft. per hr. methane

$\frac{1.6}{29.1} \times 100 = 5.5\%$ methane in the inlet gas (computed)

minus 3.6% methane outlet (analysis)

gives 1.9% methane breakdown in furnace

$0.019 \times 29.1 = 0.55$ cu.ft. per hr. methane breakdown

$0.55 \times \frac{12}{360} = 0.018$ lb. carbon released per hr. for carburizing.

Similar computations for run No. 5 give 4.0% methane in inlet and 1.3% or 0.52 cu.ft. per hr. breakdown in the furnace, equivalent to 0.017 lb. carbon.

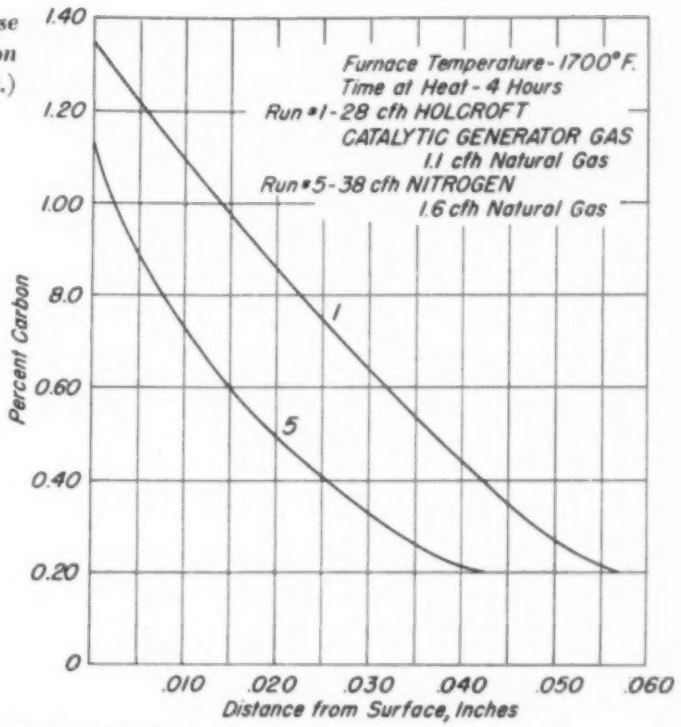


Fig. 4 — Carbon-Penetration Curves Showing Deficient Case When Nitrogen Is the Carrier Gas, Even Though Carbon Released for Carburizing Is the Same (0.017 Lb. per Hr.)

Comparison of the carbon-penetration curves for runs No. 1 and 5 (Fig. 4) shows that higher surface carbon content and deeper penetration resulted after 4 hr. when generator gas was used as a carrier than when nitrogen was the carrier, although the available carbon in the two atmospheres was practically the same, as shown by the calculations in the footnote opposite.

The amount of carbon released per hr. for carburizing with catalytic generator gas as the carrier was 0.018 lb., as compared to 0.017 lb. per hr. using nitrogen as the carrier. However, Fig. 4 shows that the catalytic generator gas run has a surface carbon concentration of 1.35%, approaching saturated austenite at 1700° F., and a normal case depth (0.051 in.) for 4 hr. at heat, whereas the nitrogen carrier gas run has both a lower surface carbon concentration (1.12%) and a lighter case depth (0.036 in.). Runs No. 2 to 4 with nitrogen carrier show more carbon released than run No. 1, but even in them the surface carbon concentrations in the carburized bars were lower than they should be.

Since all tests had sufficient carbon released for carburizing, the difference in surface carbon concentrations can be attributed to a difference in equilibrium conditions. This may be explained by examining the equilibrium percentages of CO_2 and H_2O for the atmospheres, thus:

Calculations for run No. 1 (with catalytic carrier gas) show equilibrium values of 0.06% CO_2 and 0.22% H_2O. However, this atmosphere was a stronger carburizer than the calculated equilibrium since no CO_2 was found in the analysis of exit gas.

Run No. 2 shown in Table I indicates that, when using nitrogen as a carrier gas, saturated austenite and normal case depth can be approached and may even be produced by maintaining proper furnace conditions (possibly using a larger furnace volume so that the gases may reach equilibrium before coming in contact with the stock, using a greater flow of hydrocarbon gas, or rigidly eliminating possible sources of oxygen).

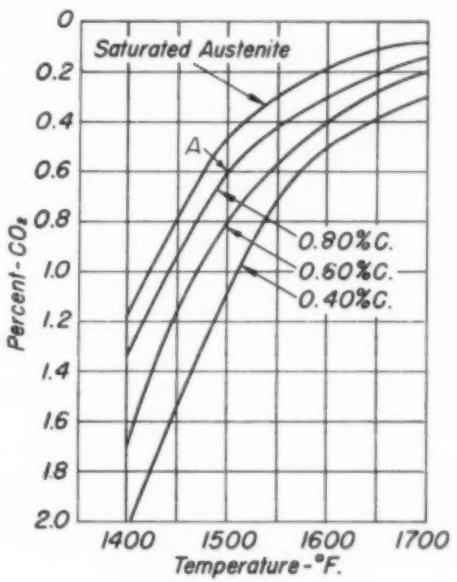


Fig. 5 — Percentages of CO_2 at Various Temperatures in Equilibrium With 0.40, 0.60, and 0.80% Carbon Steel and With Saturated Austenite. Gas contains 20% CO and is at 1 atmosphere pressure

Calculations for run No. 5 (using nitrogen as a carrier gas) show equilibrium values of 0.0001% CO_2 and 0.0008% H_2O. If the CO_2 and H_2O contents of this atmosphere were not greater than these figures, the surface carbon concentrations would be equivalent to saturated austenite at 1700° F. (1.40%). The CO_2 content of this atmosphere was too small to be measured quantitatively, but since saturated austenite was far from being produced, the atmosphere was a weaker carburizer than the calculated equilibrium.

In order to illustrate this latter point better, two test runs were conducted at 1500° F., where CO_2 contents could be measured quantitatively. At 1500° F. and a 20% CO gas, the CO_2 content of the atmosphere must be 0.5% or less to produce saturated austenite (Fig. 5). The CO_2 content of the atmosphere in test A (Fig. 6) was controlled at 0.4%. The resulting surface carbon concentration was 1.04%, which is approximately equivalent to saturated aus-

tenite at 1500° F. In test B (Fig. 6) the CO_2 content of the atmosphere was controlled at a much higher figure, at 0.7%. The resulting surface carbon concentration was 0.61% (much lower) and the case depth lighter than in test A. This surface carbon concentration tends to confirm the equilibrium values for 0.8% CO_2 in the gas and 0.60% carbon in the steel at 1500° F. (see Fig. 5).

Thus, the carbon gradients shown in Fig. 4 and 6 may be divided into two groups:

1. Runs No. 1 (Fig. 4) and A (Fig. 6): Saturated austenite at the surface and normal case depth, produced by a gas with the $CO:CO_2$ system *stronger* than the equilibrium value required for saturated austenite, that is, $\frac{(CO)^2}{(CO_2)} > K$.

2. Runs No. 5 and B: Surface carbon concentration less than that of saturated austenite and case depth less than normal, produced by a gas with the $CO:CO_2$ system *weaker* (richer in CO_2) than the equilibrium value required for saturated austenite, that is, $\frac{(CO)^2}{(CO_2)} < K$.

Fig. 6 — Concentration-Depth Curves for Carburizing 3 Hr. at 1500° F. in Carrier Gas Containing 20% CO, and With CO_2 at 0.4 and 0.7%, Respectively

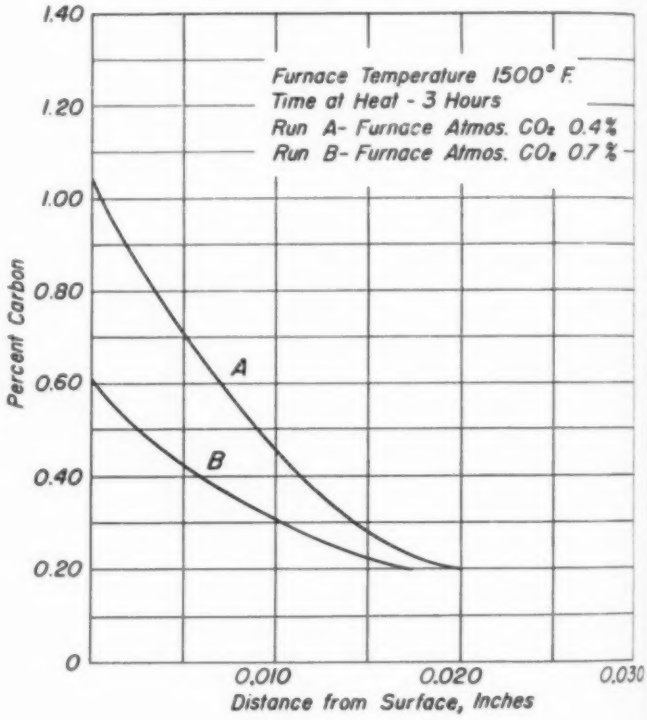
Conclusions

The results of these tests illustrate a fundamental characteristic for all commercial gas carburizing atmospheres — that is, that when the atmosphere is of low CO content, extremely small quantities of CO_2 will produce a carburized case of low surface carbon concentration and shallow case depth. As shown in runs No. 2 to 5, this condition is likely to exist when commercial nitrogen is used as the carrier gas.

It should be emphasized that this applies to practical (not theoretical) considerations. If the retort, gas, and steel in runs No. 2 to 5 inclusive could have been arranged so that *no* oxygen was present and *no* solid oxides within the retort, then the hydrocarbon addition was more than enough to satisfy completely all the theoretical demands of the steel specimen for carbon.

These tests also demonstrate the significance of the dew point in the commercial heat treating atmosphere. Referring to runs No. 1 (with catalytic carrier gas) and No. 2 (with nitrogen carrier gas), the surface carbon concentration values and case depths indicate that the two atmospheres were of approximately the same carburizing strength. Neither atmosphere contained a measurable amount of carbon dioxide. Note, however, that the dew point of the catalytic carrier gas atmosphere was +12° F., while that of the nitrogen carrier gas atmosphere was −36° F.

This variation in dew point is due to the difference in hydrogen content of the two gases. For two gases of equal carburizing strength, the one containing the higher amount of hydrogen will have the higher dew point. Thus, the concentration of the various gases must be considered when the dew point is used for measuring the carburizing strength of an atmosphere. The dew point may be used as a supplement to the CO_2 analysis, because



the dew point has a wide range of values while the corresponding CO_2 range is narrow.

In commercial atmosphere applications it is important to have a furnace atmosphere that is "measurable". The results of these tests indicate that atmospheres of extremely low CO content, such as may result when nitrogen is used as the carrier, do not contain a measurable amount of CO_2. It is considered good practice to have sufficient CO present in an atmosphere so that the equilibrium percentage of CO_2 may be measured accurately.

These tests further show that a nitrogen carrier gas will not allow as high a degree of contamination as a carrier gas high in CO, for the CO_2 and water vapor concentrations must be much lower for equilibrium conditions. This means that in commercial application the furnace and vestibule purging must be carefully controlled.

Correspondence

Blistering of Silver Plating at High Temperature

CAMBRIDGE, MASS.

To the Readers of METAL PROGRESS:

In the operation of turbines and jet engines it is desirable to maintain a bright metallic surface on some of the parts to decrease heat absorption. Silver plating has been proposed but has given considerable trouble due to blistering when heated under oxidizing conditions. Some time ago we made experiments to determine the cause of this blistering.

The samples used were strips of a high-temperature alloy, silver-plated to a thickness of from about 0.006 to 0.015 in. The conditions of electroplating were varied but seemed to be without effect on the occurrence of blistering.

Some specimens were tested by heating at 800° F. in air in a muffle furnace from 1 to 2½ hr. Such strips showed a few small blisters. Heating in air for a few hours at 1200° F. produced blisters over the entire surface of all test coupons. The size and distribution of these blisters varied. On some specimens a large number of uniformly distributed small blisters formed, about the size of a pinhead. On others a few large blisters developed, having a diameter at the base of about 0.5 in. and a maximum bulge thickness of about 0.1 in. Medium-sized and large blisters formed by lifting the silver plating from the base metal. This fact suggested that the probable cause was a reaction producing an insoluble gas, which collected under high pressure at or near the interface.

Specimens were also heated in a slow stream of purified nitrogen at 800° F. for total periods up to 10 hr., and at 1200° F. for 2 hr. This failed to produce any blistering. It was thus established that the formation of blisters required the presence of oxygen or of water vapor. The most probable reaction was the oxidation of hydrogen absorbed by the silver during plating. Another possibility, the oxidation of carbon contained in the base metal, seemed less likely.

Test coupons that had been heated in nitrogen at 800° F. and at 1200° F. were heated again in air. Blisters formed, especially at high temperatures. Previous heating in nitrogen at 800 and 1200° F. apparently was no curative.

It was next decided to test the effect of a treatment in nitrogen at higher temperatures. Sixteen test coupons representing different conditions of plating were cut in half. One set was heated in air for control purposes. All specimens thus treated formed blisters. The other set was heated in nitrogen at 1400° F. for 5½ hr. With a minor exception, all specimens were bright and smooth after this treatment. These samples were then heated in air for 5½ hr. at 1200° F. followed by another exposure to air at 1400° F. for 3½ hr. None of them developed any blisters.

These observations can be explained in the following way: If the specimens are first heated in nitrogen for a sufficient length of time and at a high enough temperature, hydrogen present is removed by outward diffusion. On the other hand, if the specimens are heated in air, oxygen diffuses into the silver before hydrogen has been reduced to a low concentration; insoluble water vapor then forms as the solubility product of oxygen and hydrogen in silver is exceeded.

This interpretation is in accord with observations by Smithells published in the *Journal* of the Royal Society of Arts, V. 86 (1938), p. 971. He found that silver can be embrittled by a process similar to the embrittlement of copper but with a reversal in the order in which oxygen and hydrogen are introduced. The phenomenon has also been observed by Martin and Parker (*Transactions*, A.I.M.E., V. 152, 1943, p. 269) who termed it "oxygen embrittlement". These authors suggest that both "hydrogen" and "oxygen" embrittlement are in a sense misnomers and may well be replaced by the term "water-vapor embrittlement".

These references apply to solid silver which had absorbed hydrogen from an atmosphere at elevated temperature. Our observations show that hydrogen absorbed during plating has the same effect. The water vapor resulting from oxidation of retained hydrogen in silver plate at high temperature seems to collect preferentially at the interface. This disrupts and buckles it. The effect of any embrittlement within the plate is apparently minor.

CARL F. FLOE and M. B. BEVER
Department of Metallurgy
Massachusetts Institute of Technology

A Neglected Problem in Physical Metallurgy

NEW YORK CITY

To the Readers of METAL PROGRESS:

The growing interest in the problem of stress-strain relationship in plastic deformation, as evidenced by a number of recent papers on that subject, compels me to draw the attention of the physical metallurgists to the fact that our knowledge remains too shaky even in the realm of elastic deformations. For example, Table I contains the values of E and G (moduli of elasticity in pure tension and pure shear, respectively) for 11 metals as given in the "Handbuch der Physikalischen und Technischen Mechanik". It shows clearly that while the individual experimenters believed their results to be precise to four digits, the variations from one experimenter to another were so large as to be almost ludicrous — more than 10% from the average value in nine of the 22 citations.

True enough, neither E nor G values enter into any specifications, and the practical designer cares but little as to whether the elastic deformation in some part of his construction amounts to 0.00020 or 0.00021 of the original dimension. But the science of metals can lay claim to no precision as long as the precise values of E and G remain unknown, in fact as long as we do not even know whether these *should* be constant!

The theory of elasticity may produce any number of theoretical equations for stress-strain relationships, but none of the symbols used can be reduced to concrete numerical values unless we know the fundamental values of E, G, K and Ψ, where K is the modulus of elasticity in uniform compression and Ψ the ratio of the radial contraction to axial elongation in pure tension.

These "constants" are connected by strictly theoretical relationships

$$\Psi = \frac{E}{2G} - 1 = \frac{1}{2} - \frac{E}{6K}$$

developed by French mathematicians about 125 years ago. At that time it was apparently proven by Poisson that Ψ must always equal 0.25. That last "proof" was found to be false and experimental determinations of Ψ by various methods have shown it to vary between 0.20 and 0.49. Likewise the "known" values of K, E and Ψ certainly do not fit the above theoretical formulas. Nevertheless their validity was never questioned, as far as the writer can determine.

Of all four terms mentioned only K, the modulus of elasticity in uniform (hydrostatic) compression, *must* be a constant, and thanks to the painstaking investigations of P. W. Bridgman of Harvard we know it with a precision of 0.1 to 0.2% for all the common pure annealed metals, and of 1 to 2% for the less common ones. It is quite possible that E and Ψ are not true constants, but merely balance each other while varying through a considerable range.

Apart from the question regarding the validity of the fundamental relationships, we should consider the most neglected one regarding the so-called "pure tension", for it must be evident that no way exists for the loading of either a test bar or a structural member in "pure tension". Consider the usual test bar with threaded heads: We apply a pressure to the threads and transform it into a tension which propagates from one atomic layer to another. If that propagation takes place instantaneously and entails no loss of stress from one layer to another, we might consider the loading to proceed in "pure tension". But the absence of such lag has yet to be proven.

Table I — Extreme Experimental Values of Moduli in Tension and Shear; Kg. Per Sq.Cm. $\times 10^6$

METAL	E; MODULUS IN TENSION			G; MODULUS IN SHEAR		
	MIN.	MAX.	RANGE*	MIN.	MAX.	RANGE*
Aluminum	0.6570	0.7540	6.9	0.2329	0.3350	18.0
Copper	1.0520	1.2550	8.8	0.3587	0.4780	14.2
Gold	0.5585	0.9800	27.5	0.2500	0.3950	22.3
Iron	1.8875	2.1740	7.1	0.7340	0.8260	5.9
Lead	0.1493	0.1803	9.3	0.0550	0.0814	19.4
Nickel	2.0300	2.3900	8.1	0.7300	0.9518	13.2
Palladium	0.9709	1.1620	8.9	0.4613	0.4900	3.1
Platinum	1.5520	1.7190	5.1	0.6585	0.7240	4.8
Silver	0.7010	0.8060	7.0	0.2467	0.2955	9.0
Tin	0.4100	0.5580	15.2	0.1530	0.1810	8.4
Zinc	0.8730	1.2700	18.6	0.1614	0.3880	41.5

*Per cent variation from the average.

If we suppose that a lag exists and that it is proportional to the actual stress — just as the absorption of light by a semitransparent body is proportional to its intensity — we may derive an expression (parallel to the optical equations) for the ratio or stress at the surface to average stress as follows

$$\frac{S_{surface}}{S_{average}} = \frac{r^2a^2}{2(e^{ar} - 1 - ar)}$$

where r is the radius of the test bar and a is the lag factor.

Now, if we suppose that in the standard test bar the drop a from surface to the center is -0.10 (10%), the ratio of the true surface stress to the average stress would be 1.035, and the same would apply to the ratio of the true E to the apparent E. Had we taken test bars 2, 3, 4 and 5 times the standard diameter, the ratios would run: 1.069, 1.103, 1.138, 1.174. In other words the apparent E would continuously decrease, provided the material were identical.

The formula suggested above is merely tentative, but I believe that any other reasonably derived one that would not lead to incongruent results would show a dependence of the apparent modulus in tension upon the diameter of the piece tested. Until such a point as this is determined, we will not attain much knowledge of elastic deformation.

Any investigation to discover this data must comprise some work on compressibility. For no matter how precise Bridgman's data are, there are still plenty of gaps in regard to the effects of alloying and working. Bridgman reported, for instance, that solid solutions show such a strong hysteresis in compression that, with the exception of nichrome, he could publish no compressibility data for alloys. That hysteresis in compression was by-passed by metallurgical physicists as if it were a mere nuisance. Most likely it hides the key to the true understanding of the nature of alloys.

MICHAEL G. CORSON
Metallurgical Consultant

Mathematical Expressions in Metallurgy

TORQUAY, ENGLAND

To the Readers of METAL PROGRESS:

I myself use a dialect speech — to those who understand it — when it is more expressive, and have therefore no complaint against those who use mathematics for a similar good reason. However, I get the impression that mathematics is sometimes used in metallurgy by writers who are dreaming about what never was, or are unable or too lazy to mint their ideas into current speech.

To those who bully me with a show of "indispensable" mathematics I quote Faraday. The results of his electrical experiments are stated in plain language, as Faraday had no mathematics, but Clerk Maxwell (who gave them a mathematical form) said it was the merest translation from one language to another; there was nothing to add and nothing to alter.

I recently saw a mathematical treatment of shrinkage in ingots, which concluded that after very slow freezing ingots would be pipeless! And the writer of this nonsense had worked (?) for two years in a steelworks!

Your Oliver Wendell Holmes (the Professor at the Breakfast Table) wrote some prickly lines:

"A young man with a grave mathematical look
Made believe he had written a wonderful book;
And the Royal Society thought it was true
So they chose him right in, a good joke it was too."

I quote from memory; "grave mathematical" could be replaced by "bright metallurgical" as required.

HARRY BREARLEY

War Department's Research and Development Program

WASHINGTON, D.C.

To the Readers of METAL PROGRESS:

While it is generally understood that the extensive research sponsored by the American Government during the late war and conducted in the laboratories under its direct operation has been considerably curtailed, it is not so widely known that a very large number of problems are still being investigated, and that this program has been placed in the highest priority. Such activities are utilizing, on contract basis, many civilian educational and industrial laboratories. The duty of the Research and Development Division of the General Staff, U. S. Army, is to coordinate such activities and to attract as much civilian talent, facilities and assistance as required. Such scientists and civilian researchers will be given the greatest possible freedom to carry on their work.

In order that qualified persons may become acquainted with the manifold activities under way and contemplated, a rather elaborate outline of the program for fiscal year 1949 has been prepared and may be secured by addressing the War Department, General Staff, The Pentagon, Washington 25, D.C. From this document a few notes on important unsolved metallurgical problems are appended:

Light weight pipe for oil and gas distribution.

Light weight mats for aircraft with tracked-type landing gear.

Electroforming of searchlight reflectors.
Containers for liquid oxygen.
Light alloy cartridge cases.
Improved gun steels.
Improved armor in all categories.
Improved components for small arms.
Strong, light weight die castings for quartermaster's items.
Special alloys for electron tubes and electrical devices.
Magnesium sheet and extrusions of superior properties for aircraft structure.
Materials of specific stress-rupture properties at definite high temperatures.
Information on mechanical properties at very low temperatures.
Improvement of strain gages.
Sheet material for aircraft use at 1800° F. plus.
Methods for forging alloys and components of gas turbines.
Evaluation of new heat treating techniques.
Exploration of molybdenum, titanium and zirconium as structural and mechanical metals.

From this by-no-means complete list of projects, primarily metallurgical in nature, it can be seen that the development of advanced weapons, techniques, materiel and counter-measures — in fact, the future defense of America — needs the closest contact between the leaders in metallurgical industry, science, technology and education, and the responsible officers in the War Department.

E. A. ROUTHEAU, *Colonel*, G.S.C.
Chief, Research Group
General Staff, U. S. Army

Width of Crack Discoverable by Deep Etching

FOREST HILLS, PA.

To the Readers of METAL PROGRESS:

We were greatly interested to read Mr. Lauderdale's note in the November issue in which he indicated that a very fine crack may not be visible under the microscope or demonstrable by magnetic particle testing. This fact carries important implications, in view of the extent to which the magnetic method is used today for just this purpose.

In 1926 (*Transactions*, A.S.S.T., V. 10, p. 9) F. P. Gilligan and the writer discussed some interesting uses of the deep etch in a paper entitled "Macroscopic Examination of Iron and Steel". Figure 18 of that paper pictured one throw of an automobile engine crankshaft which had broken in fatigue. On deep etching a longitudinal section through the throw, next the failure, two additional fatigue cracks were disclosed, indicating that at least three had started and progressed simultaneously in service at this zone in the crankshaft. Neither of the two cracks could be seen at 100 diameters and higher on the surface of microspecimens removed from the mating half of the deep-etched specimen, either directly after polishing or directly after the usual nital etch for microscopic examination. However, on re-examination several days later, the cracks were easily visible, due to seepage of microscopic droplets of oil from the cracks.

It may be, then, that the long-known liquid penetration and seepage methods, of which "Zyglo" is one much used today, might also be useful to demonstrate the presence of very fine cracks providing, of course, the penetrant liquid can actually penetrate the crack. In our crankshaft the periodic reversals of stress and deflection acted positively to pump the crankcase oil into the crack.

J. J. CURRAN

Fractichthyocephalus

BALTIMORE, MD.

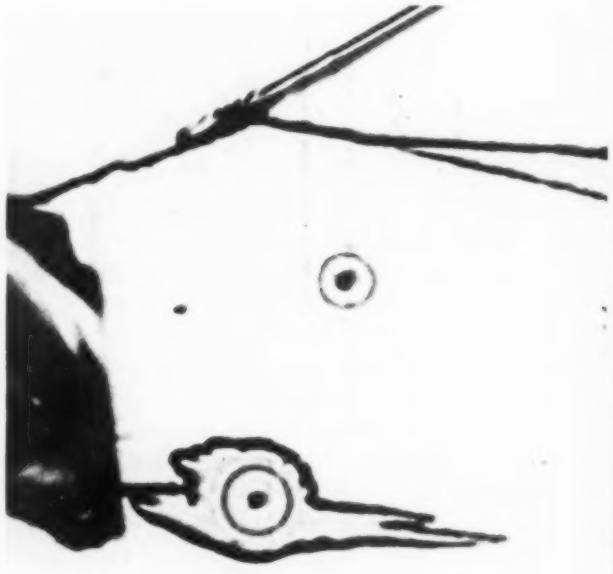
To the Readers of METAL PROGRESS:

An eel-like fish (Ichthyocephalus) of the family Monopteridae (syn. *Flutidae*) has the head distinctly fishlike and the shoulder girdle joined directly to the skull. It is usually treated as a suborder of Symbranchia (Webster), prefix "fract-" connoting habitat in fractographs (author's license).

Specimen in figure caught in act of urping eyelike bubbles prior to gorging on choice seaweed.

F. K. LANDGRAF, JR.
C. O. WORDEN, JR.
Laboratory of C. A. Zapffe

Untouched Cleavage Facet of Metallic Antimony, Showing Twins (Vertical Bands) and Piscatorial Phenomenon (loc. cit.); *1250* ×



REVERE COPPER
and COPPER BASE ALLOYS
For Use With
LIQUID OXYGEN

★ ★ ★

COPPER and its alloys have long been favored by metal fabricators as materials of construction for pressure vessels, distillation columns, heat exchangers and other equipment for chemical plants. The ability of these alloys to be readily formed and easily joined by conventional methods, coupled with their good mechanical properties and high corrosion resistance, have made them preeminent in many applications.

However, the manufacturer of oxygen producing or handling equipment must consider more than the above-mentioned properties. He must insist that the materials used be immune to any adverse effects low temperatures may have. Many commercial alloys become increasingly brittle and lose their ability to withstand sharp blows as the temperature drops. But here again, there need be no worries with respect to copper and its alloys. Note the improvement at low temperatures in strength, ductility *and* resistance to impact for three copper base alloys:

Alloy (Annealed)	Temperature, °F.	Tensile Strength, psi.	Elongation, % in 2 in.	Impact Resistance—ft/lb, Izod Specimens
Deoxidized Copper	Room	31,400	48	43
	—292	58,000	58	50
Cupro Nickel, 30%	Room	70,800	41	90
	—292	112,700	51	97
Cartridge Brass, 70%	Room	51,100	49	66
	—292	73,500	75	79

(Tests on 0.25 in. diameter specimens)

Other Revere alloys, such as Herculoy (High-Silicon Bronze, A) show similar excellent properties at depressed temperatures.

Therefore, in designing oxygen plants, to play safe, specify copper-base alloys. Revere's Technical Advisory Service will be glad to assist in the selection of the proper alloys to meet your requirements.

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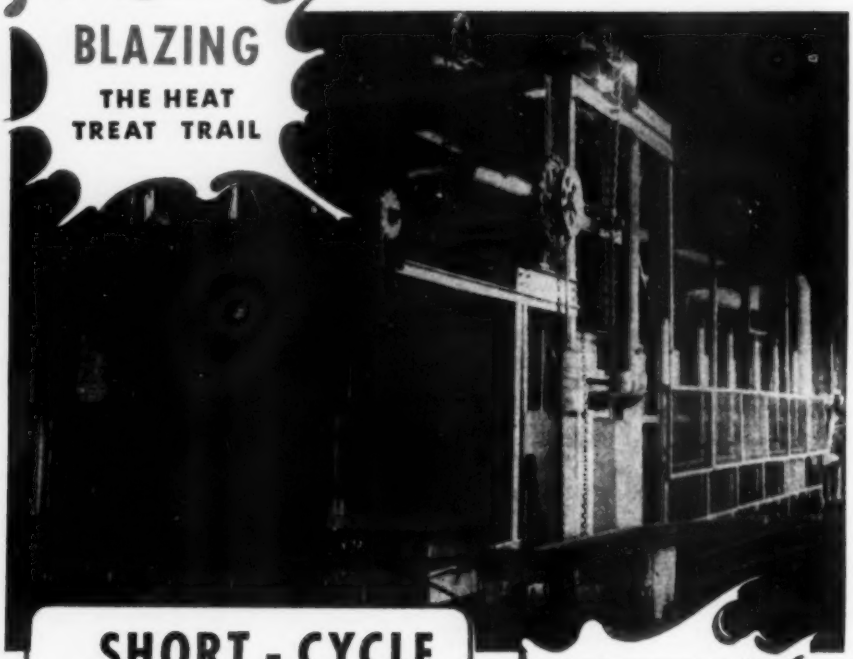
BLAZING
THE HEAT TREAT TRAIL



SHORT-CYCLE MALLEABLE ANNEALING FURNACE

Another example of Holcroft "trail blazing"—the first radiant tube continuous furnace for short-cycle malleable annealing, installed more than 10 years ago and still producing economically.

DEVELOPED BY *Holcroft* IN 1936

Short-cycle malleable annealing is a fast, economical process which offers the following advantages to large-volume manufacture:

- The process requires as little as *14 hours*, as compared to *several days* for other methods. This means reduced inventories and faster shipments.
- It produces *clean, scale-free work* which can go directly to shop or assembly without further processing.
- It permits the use of *light-walled containers* — reduces dead weight by as much as 400%, and cuts fuel bills correspondingly.
- It enables large and small castings to be handled simultaneously.
- Compared to other methods, it gives several times the production per unit of floor area.

Although continuous furnaces are most frequently used, this process is also successfully applied to batch-type furnaces. As with all Holcroft furnaces, each installation is *designed individually* for the specific application, thus meeting every requirement of production and quality with maximum over-all economy.

In ordering production heat treat furnaces for ANY need, it will pay you to take advantage of Holcroft engineering leadership. And remember — Holcroft offers you *complete metallurgical and engineering service*, from individual furnace design through the trial run in your plant.

PRODUCTION HEAT TREAT FURNACES FOR EVERY PURPOSE

SINCE 1916

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Canada: Walker Metal Products, Ltd., Walkerville, Ontario

Personals

Carpenter Steel Co. announces that **Norman C. Einwechter**, assistant to the vice-president, will be in charge of the Philadelphia-Reading territory with Philadelphia headquarters.

Jack W. Hobbs, formerly sales engineer of Akron Welding & Spring Co., is now sales engineer of the Rogers Tool & Die Co., Inc., Akron, Ohio.

Joslyn Mfg. and Supply Co. announces the appointment of **James A. Downey** as its sales representative for the Philadelphia, Baltimore and Washington districts.

H. H. Benninger, formerly assistant chief metallurgist of Chrysler Corp., Detroit, is now connected with the Peninsular Steel Co. as metallurgical contact engineer.

L. J. Gould, formerly assistant chief engineer of construction of Bethlehem Steel Co., has been appointed chief engineer of construction on the retirement of the former chief engineer, **R. B. Gerhardt.**

A. O. Wood will join the Chicago office of Ohio Crankshaft Co. as district engineer under the new project of adding engineering service to Chicago facilities.

J. Roy Gordon and **Herbert G. Fales** have been elected vice-presidents of International Nickel Co. of Canada, Ltd., and **T. H. Wickenden** has been elected a vice-president of The International Nickel Co., Inc.

Edwin C. Davis, formerly assistant professor of metallurgy at Virginia Polytechnic Institute, is on active duty in the Navy and is at present an executive officer of U.S.S. Bayfield in the western Pacific.

Formerly a teaching assistant in mechanical engineering at California Institute of Technology, **Howard N. Farmer, Jr.,** is now metallurgist for the Security Engineering Co., Inc., of Whittier, Calif.

P. M. Sanders is now a consultant in metallurgy in the southern California area.

Resigning as chemical and process engineer from the Lima, Ohio, plant of Westinghouse Electric Corp., **Robert L. Ruleff** has taken a position with Gilbert Tramer as sales engineer for southern Ohio.

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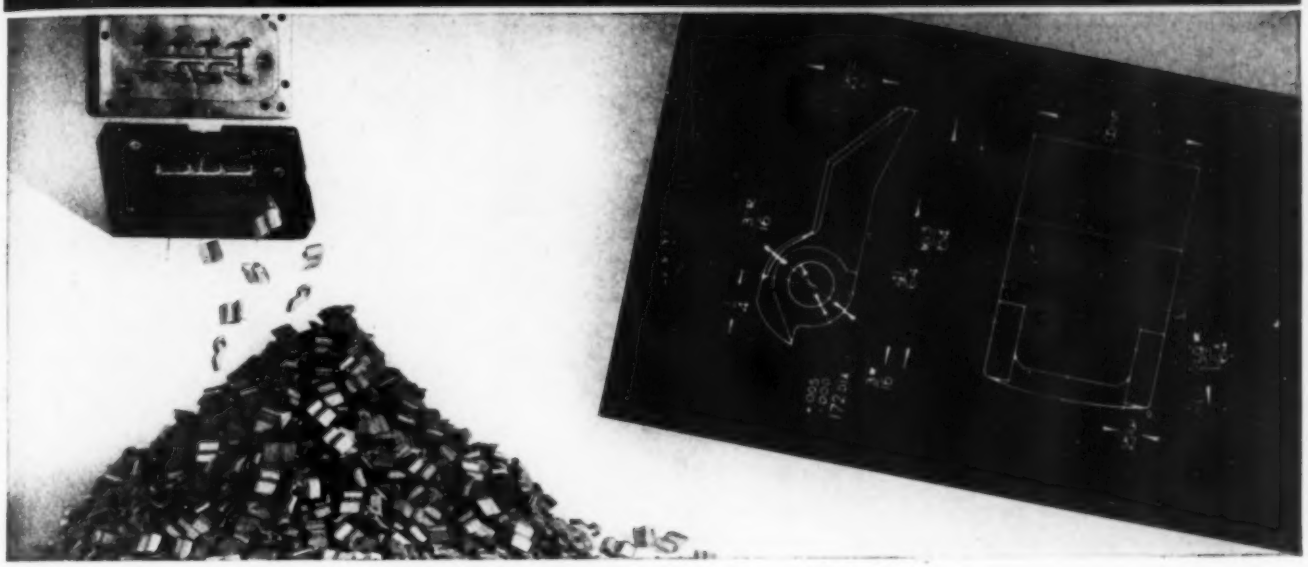

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Personals

George N. Vitt, formerly assistant to the president of the A. F. Holden Co., New Haven, Conn., has been appointed member of the board of directors, secretary and manager of John Ek Industries, Inc., of Guilford, Conn.

Thomas G. Digges, who has been a member of the metallurgical division of the National Bureau of Standards since 1920, has been appointed chief of its thermal metallurgy section recently.

E. C. Hoenicke, general manager of the Eaton Mfg. Co.'s foundry division, Detroit, has been elected to the administrative council of the National Founders Assoc.

Andrew Van Echo, formerly technical service representative and chief inspector for Joslyn Stainless Steel Co., is now metallurgical engineer for Wm. E. Pratt Mfg. Co., Joliet, Ill.

Swan-Finch Oil Corp. announces the appointment of **Anthony J. Zino, Jr.,** as assistant sales manager of the industrial sales division with headquarters in New York City. Mr. Zino had previously represented E. F. Houghton & Co. and Lubri-Zol Corp. in the New York area.

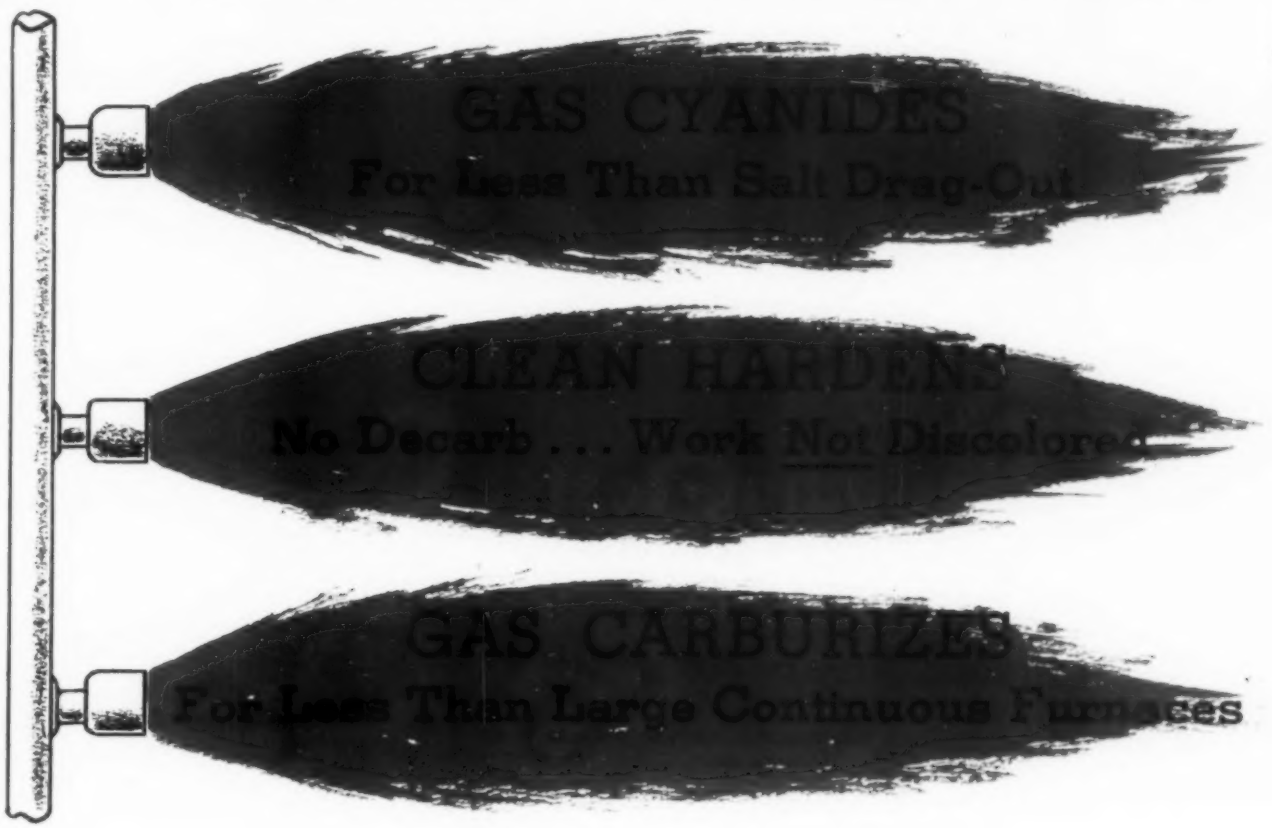
Federated Metals Division, American Smelting and Refining Co., announces the promotion of **John S. Selfridge, Jr.,** to the superintendency of the San Francisco plant. Mr. Selfridge has been with Federated Metals for seven years, first as assistant metallurgist and then as assistant superintendent.

Atlas Steels, Ltd., announce the appointment of **H. B. Chambers** as chief service metallurgist. He joined the Atlas Steels organization in 1931.

William T. Strickland has been appointed sales engineer at the Chicago office of the Timken Roller Bearing Co. He joined the Timken Co. in 1946 on his release from the Navy.

J. R. Thorpe, formerly with Dow Chemical Co. as a research and development engineer in the magnesium division, has joined with **D. C. Law** and **R. V. Miller** to form Magline, Inc., Pinconning, Mich., to manufacture all-magnesium handling equipment.

MULTI-PURPOSE BATCH TYPE FURNACE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CLEAN HARDENS
No Decarb . . . Work Not Discolored
GAS CARBURIZES
For Less Than Large Continuous Furnaces

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Cutler-Hammer, Inc. of Milwaukee, Wis., selected extruded Ampco Metal, Grade 22, for bumper buttons in electrical switch boxes — because of its unique wear-resistant qualities.
Everything under control—
including costs!

—when you use wear-resistant extruded Ampco Metal

20 million impacts — without showing appreciable wear! That's the duty requirement set up by Cutler-Hammer, Inc. for the bumpers in electrical switch boxes. They needed a metal to do that job — at the rate of 30 impacts a minute (maximum). Extruded Ampco Metal (Grade 22) was selected. It did the job and passed inspection without a sign of peening or mushrooming. Its exceptional durability made important savings in maintenance and replacement costs.

Yes, the famed performance advantages of Ampco Metal more than met the operating requirements. And the production advantages of using extruded stock were three-fold:

1. Stock sizes closely parallel requirements — reducing waste.
2. Close size cuts machining time and tool costs.
3. Smooth surface and compact structure cuts rejections caused by hidden flaws.

Two grades of Ampco Metal and two grades of Ampcoloy (industrial bronzes) are regularly produced in extruded form by Ampco. Rods in a complete range of sizes are available for immediate shipment. Scores of companies now use extruded Ampco rod for product improvement and production economy. Give your plant this double advantage. For further data, write for Bulletin 64A today!

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Specialists in engineering, production, finishing of copper-base alloy parts.

Ampco Metal, Inc.
Dept. MP-2, Milwaukee 4, Wis.
Field Offices in Principal Cities
A-30

Personals

W. J. Parsons, secretary-treasurer of the Los Angeles Chapter of the American Society for Metals, has been appointed by Pacific Scientific Co. to the position of sales manager of the heavy industrial division in which capacity he will handle products of Wilson Mechanical Instrument Co., Hevi Duty Electric Co., Lindberg Engineering Co., Tinius Olsen Testing Machine Co. and Induction Heating Corp. on the West Coast.

James B. Hess, formerly of the magnesium laboratories, The Dow Chemical Co., has accepted an appointment as metallurgist at the Institute for the Study of Metals, Chicago, Ill.

William J. Collins, formerly metallurgist at the Gary works of Carnegie-Illinois Steel Corp. and St. Louis district manager for the Claud S. Gordon Co., is now district sales representative for the Lapham Hickey Co. of Chicago for northern Indiana and western Michigan.

Nicholas A. Wagner, formerly plant chief chemist of Reynolds Metals Co., Grand Rapids, Mich., has been transferred to Louisville, Ky., where he will assume the position of development metallurgist.

Edwin B. Johnson is now employed by the Kaiser-Frazer Corp. at Willow Run, Mich., as a metallurgist.

Paul A. Cushman, formerly metallurgist and test engineer with McGill Mfg. Co. of Valparaiso, Ind., is now chief engineer with the L & S Bearing Co., Oklahoma City, Okla.

After receiving his M.S. degree from Columbia University in June 1947, **J. E. Chafey** has been engaged by the Chase Brass and Copper Co. as one of its research metallurgists at the metal works plant in Waterville, Conn.

Chauncey E. Hathaway has been transferred by the U. S. Rubber Co. from its plant at Mishawaka, Ind., to Chicago, where he is to be in charge of physical testing and control of new plastic products.

Colin G. Chisholm, chairman of Oregon Chapter in 1943, has terminated his connection with Columbia Steel Co., San Francisco, and has joined Woodbury & Co., Portland, Ore., as manager of the mild steel department.

YOU CAN SAVE 4 WAYS

with Welded Alloy

ANNEALING EQUIPMENT

These Annealing Boxes Saved Remarkably on Fuel and

INCREASED FURNACE OUTPUT 100%

Here is a typical case from actual plant records showing how substantially Pressed Steel Company annealing boxes step up output of furnaces. This installation of 22 stands of our sheet alloy boxes, in a well known malleable foundry, were used to replace 18 stands of cast boxes. In addition to doubling the output, they furnished these four additional savings:

1) FUEL SAVING — Made of light gauge welded sheet alloy, they require less fuel and time to attain pot heat.

2) LABOR SAVING — Handle easier and faster.

3) REPLACEMENT SAVING — Some installations of "Pressed Steel" annealing boxes have been in constant service for 20 years.

4) SPACE SAVING — Being less bulky than cast boxes, "Pressed Steel" sheet welded equipment saves room.

Upon request to this office, your local "Pressed Steel" representative will furnish you data on our heat-treating, carburizing and other welded alloy equipment for high-temperature and corrosive applications in foundry and steel mill.

Send for Our Bulletins

THE PRESSED STEEL COMPANY

of WILKES-BARRE, PENNSYLVANIA

Industrial Equipment of Heat and Corrosion Resistant WEIGHT-SAVING *Sheet Alloys*

☆ ☆ ☆ OFFICES IN PRINCIPAL CITIES ☆ ☆ ☆

"Brake Shoe Research serves you today and anticipates tomorrow"
Wm. B. Given, Jr., President

CASTINGS PILOTED HERE
give you
THE BEST FOR YOUR PURPOSE

CASTINGS BY BRAKE SHOE
• Meehanite® • ABK Metal
Gray Iron, plain or alloyed

• In this completely equipped experimental foundry you can get impartial experience-based recommendations as to which of these three types of metals will serve you best for your cast parts. It is one building of a group at Mahwah, N. J., the national research headquarters of American Brake Shoe Company.

Whichever metal proves best for you, Brake Shoe foundry techniques can benefit you in both pilot and production foundries at Mahwah, N. J., and in the company's production foundries at Melrose Park, Ill., and Baltimore, Md.

At these plants, castings can be made in widely-used types (light, medium or heavy weight, green or dry sand or all core assemblies) including intricate and special types. Write us about your needs; let us tell you what we at Brake Shoe can do to meet them.

6205

Brake Shoe
BRAKE SHOE AND CASTINGS DIVISION
230 PARK AVENUE, NEW YORK 17, N. Y.

Personals

George F. Briner ⊖, formerly chief test engineer at Jacobs Aircraft Engine Co., is now a member of the engineering department of Gilbert Associates, Inc., Reading, Pa.

J. Paul Ahlbrandt ⊖ has left Bendix Home Appliances, Inc., South Bend, Ind., to take the position of director of manufacturing at the Hamilton Mfg. Co., Two Rivers, Wis.

George M. Yoder ⊖, formerly in the engineering division, Air Materiel Command, Wright Field, Dayton, Ohio, has accepted a position as project engineer, Working Committee, Aeronautical Board, Washington, D. C.

John A. Patterson ⊖, who graduated from Rensselaer Polytechnic Institute in June 1947, has been made office manager for a field crew of the Geotechnical Corp. which is engaged in making a seismograph survey.

Formerly chief metallurgist of Eversharp, Inc., **W. T. Snyder** ⊖ is now chief engineer of Herff-Jones Co., Indianapolis.

Joseph B. Meierdirks, Jr., ⊖, formerly research engineer of Commonwealth Engineering Co., Dayton, Ohio, is at present research metallurgist, Allegheny Ludlum Steel Corp., Watervliet, N. Y.

J. C. Holmberg ⊖, who was formerly metallurgical engineer at Tulsa Boiler & Machinery Co., has joined Marion Power Shovel Co., Marion, Ohio, as welding engineer.

Leonard W. Dean ⊖ has joined the staff of the Vascoloy-Ramet Corp., North Chicago, Ill., where he will direct the promotion of precision casting of the alloy Tantung. Mr. Dean was previously a consultant on precision casting.

On graduation from Carnegie Institute of Technology, **Bruce M. Shields** ⊖ became associated with Carnegie-Illinois Steel's south works.

Jean Louvier ⊖ has been transferred by Western Cartridge Co. from the research division to mill products inspection, East Alton, Ill., where he will assist in the establishment of an inspection group in the castings shop.

After leaving Republic Aviation Corp., **John A. Shandley** ⊖ joined General Motors Institute where he is an instructor in metallurgy.

Over 15,000 hours at 1575° F !

Cast NICHROME* doubles the life and halves the cost of Heat Treating Trays

To produce THE STRONGEST ANCHOR CHAIN KNOWN, Baldt Anchor, Chain & Forge Company, Chester, Pa., employs the U. S. Navy developed process known as DI-LOK. Alloy links are forged and heat treated to maximum strength. The resulting chain readily meets U. S. Navy test loads which are 50% greater than those prescribed by the American Bureau of Shipping for cast steel chain.

For one hour, links travel in cast Nichrome trays through a furnace temperature of 1575°F., then emerge into room temperature. The trays are emptied, and twenty minutes later, reloaded, start their journey through the furnace again.

In continuous operation, each Nichrome tray is subjected to 18 heating and cooling cycles every 24 hours—and is in contact with furnace temperature for a total of 18 hours.

Under these severe conditions, the tray gives trouble-free service for more than 15,000 hours of furnace operation, at an estimated tray cost of one cent per hundred pounds of heat treated product...little more than half the cost of substitute alloys.

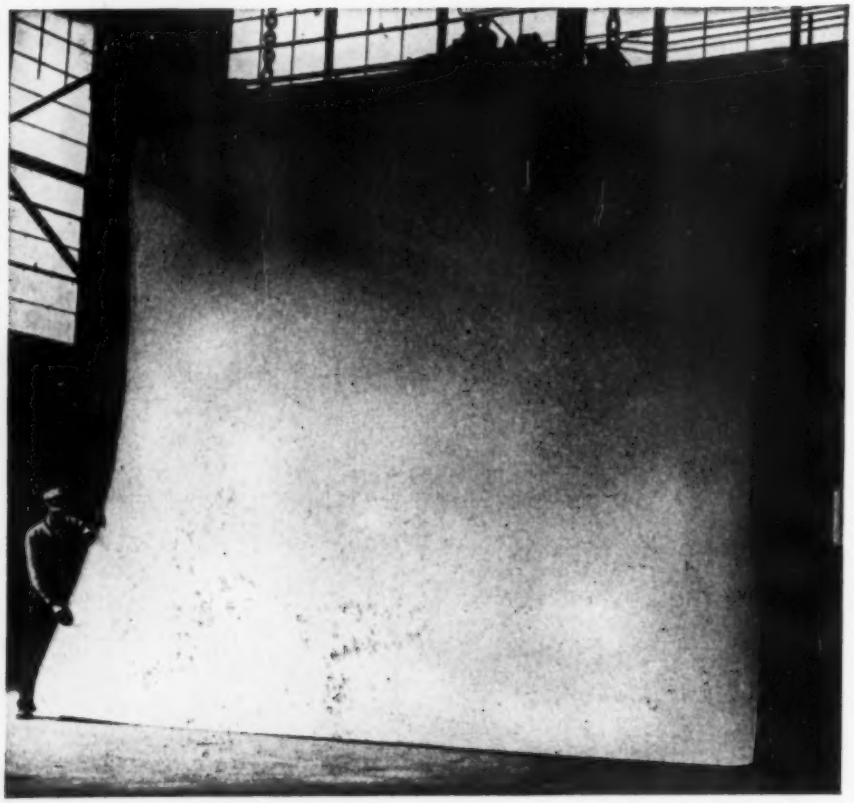
Baldt has found no other alloy comparable to Nichrome for this grueling job.

Bring your heat treating problem to us. Not only have we had more than 30 years' experience in engineering and casting high heat-resisting nickel chrome alloys, but we are the sole makers of Chromax*, Cimet*, and the world-famous Nichrome*.

Driver-Harris
COMPANY
HARRISON, N. J.

BRANCHES: Chicago • Detroit • Cleveland
Los Angeles • San Francisco • Seattle

*T. M. Reg. U. S. Pat. Off.



When CARLSON Says LARGE STAINLESS PLATE We Mean LARGE!

This type 304 Stainless Steel plate measures 203" x 168" x ½", to be pattern cut to customer specifications in the Carlson plant.

Produced to chemical industry standards of quality, this plate, weighing 5,180 lbs., is a typical example of the ability of G. O. Carlson, Inc. to meet your needs in a wide variety of stainless analyses.

Remember too, that Carlson can supply you as readily with stainless plates, forgings, billets, sheets, bars, rings, etc. in ANY SIZE, small or large, pattern cut if you desire. Most orders can be filled right out of stock.

When it's Stainless GO to CARLSON first.

Do you receive the G. O. Carlson, Inc. weekly stock list? If not drop us a line. No obligation.

G. O. CARLSON, INC.

Stainless Steels Exclusively

300 Marshalton Road, Thorndale, Pa.

Personals

Edward C. Zuppann, who graduated from the University of Minnesota in 1947, is now cupola foreman at Wilson Foundry and Machine Co., Pontiac, Mich.

Wieslaw Jedrzejowski is now development and design engineer with Powers Regulator Co., Chicago, Ill.

Franklin H. Fowler, Jr., has recently joined the staff of Lessells and Associates, Boston, to perform fundamental research in the theory of metal fatigue and mechanical engineering consulting work.

Albert J. Fischer is production manager of Adamas Carbide Co. in Long Island City, N. Y.

Graduating from the University of Illinois in October 1947, **LeWayne N. Wall** is now employed as metallurgist in the research laboratory of the Combustion Engineering Co., Chattanooga, Tenn.

Anon Srivardhana is a graduate student in process metallurgy at the University of California, Berkeley, Calif.

James C. Wilkins has joined the research department of the American Rolling Mill Co. at Middletown, Ohio.

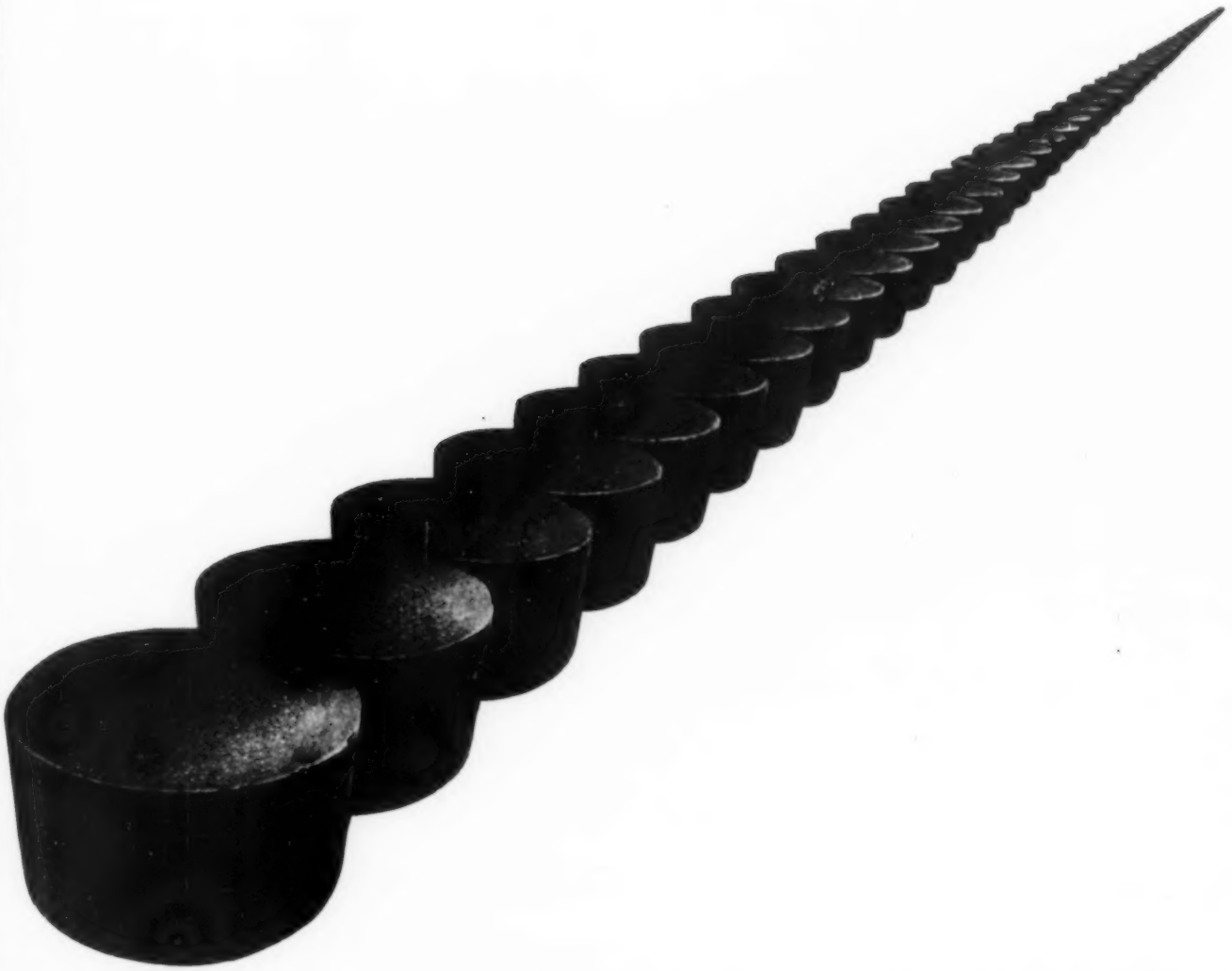
Upon leaving the Los Angeles Foil Division of Reynolds Metals Co., **Ruth A. King** has become associated with the Tricasal Co. of Los Angeles as office manager.

John Snyder has been transferred to the technical department of the Remington Arms Co., Bridgeport, Conn.

Wayne A. Reinsch, who has recently completed work for his M.S. in metallurgical engineering at Stanford University, has joined the research department of Pacific Can Co. in San Francisco.

T. G. Gilley, who was plant metallurgist at the Western Electric Co.'s electronic shops in New York City during the war, has been transferred back to the Kearny plant where he is in charge of the metallurgical laboratory.

Robert W. Brown is now with the Westinghouse Electric Co. at East Pittsburgh, Pa., as metallurgical engineer in the materials engineering department.



Timken used 45,000 Carbon Mold Plugs

...THEN SAID:

*"Carbon plugs are never out-of-round and are consistently accurate in dimensions. They are structurally strong and may be handled without damage . . . can be hammered into place in the mold opening without being crushed. A large percentage may be employed a second or third time.

"Their use has eliminated 90 pct of the leakers . . . absence of leakers has reduced steel loss to a minimum and has prevented the burning of mold buggies and railroad ties and rails under the mold buggies. Reliance on the plugs has improved pouring conditions by eliminating stop-pours, skulls, sticking blackheads and other pouring difficulties.

"Carbon mold plugs do not spall. There can be no refractory absorbed into the ingot from the plug, which practically eliminates the possibility of inclusions from the mold plug. Little or no carbon pickup is noted in ingots of steels over 0.10 C.

"Elimination of burn-outs in the plug holes has improved mold life by 10 pct. There is no contamination of soaking pit bottoms if the carbon plugs adhere to the ingot bottom. As compared with any other plug of the same size, the carbon type is light and very easily stored or handled . . . a decided advantage has been gained in producing alloy steel of the best quality."

**From an article entitled, "Carbon Mold Plugs . . . In Alloy Steel Production" which appeared in the November 27, 1947, issue of* Iron Age.

NATIONAL CARBON COMPANY, INC.

Unit of Union Carbide and Carbon Corporation
30 East 42nd Street, New York 17, N. Y.

UCC

Division Sales Offices: Atlanta, Chicago, Dallas, Kansas City, New York, Pittsburgh, San Francisco

For reprints of this article on carbon mold plugs, write to National Carbon Company, Inc., Dept. MP

THIS PHOTOMICROGRAPH of WELDRAWN* tubing MEANS *money in your pocket...*

It shows just how very good, LOW COST Superior WELDRAWN Tubing is.

To the design engineer, WELDRAWN means *dependable* small tubing at prices that will more than satisfy cost engineers.

To the purchasing department WELDRAWN means fine small tubing (.010" to .625" O.D. Max.) *at low cost* . . . readily available to exact specifications.

To the metallurgist WELDRAWN, as shown in this photomicrograph of Type 304 stainless steel, magnification 50X, means the complete recrystallization in the weld area to produce a homogeneous tube structure.

Turn to the Superior Tube Company's WELDRAWN for the finest small tubing at a cost that *is* a substantial saving. There is a Superior WELDRAWN booklet available. Write for your copy today.

WELDRAWN tubing is supplied in—
Stainless—A. I. S. I. 304, 309, 310, 316, 347, 430 & 446.
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Glass Sealing Alloys:
27% Chrome Stainless
36% Nickel Iron (Invar)
42% and 52% Nickel Iron

*Reg. U. S. Trademark—Superior Tube Co.

THE BIGGER NAME IN SMALL TUBING Superior (.010" to 5/8" O.D. MAX.)

SEE OUR CATALOG in

SUPERIOR TUBE COMPANY
2008 Germantown Ave.
Norristown, Pennsylvania

For Superior tubing on the West Coast, call PACIFIC TUBE COMPANY, 5710 Smithway St., Los Angeles 22, Cal. ANgelus 2-2151

Personals

William B. Price, for many years chief chemist and metallurgist (and latterly director of research) for Scovill Mfg. Co. of Waterbury, Conn., has retired from active service. **F. M. Barry** is now head of the chemical and test department.

The retirement of **D. F. Axelson** from the position of vice-president in charge of manufacturing of Axelson Mfg. Co. has brought about the appointment of **R. M. Pease**, formerly vice-president and manager of the company's plant in St. Louis, Mo., to the position of vice-president and assistant general manager. Mr. Pease is now at the main plant in Los Angeles.

Arthur J. Williams, who for the past four years has been affiliated with the Bureau of Mines, has been appointed to the staff of Battelle Memorial Institute, Columbus, Ohio, where he will conduct research in welding technology.

Morse Chain Co. announces the appointment of **E. W. Deck** as manager of the Ithaca, N. Y., plant. Mr. Deck had previously been with Borg-Warner Corp. as consultant on manufacturing research, and manager of Trent Tube Mfg. Co.

After 40 years as metallurgist for the John A. Roebling's Sons Co., **Henry C. Boynton** has been appointed head of the new metallurgical department at Temple University, Philadelphia.

Percy E. Landolt, who has been associated with the development of lithium products for over 20 years, has been elected director and executive vice-president of Lithium Corp. of America, Inc., and its subsidiary, Metalloy Corp. of Minneapolis, Minn.

The Champion Rivet Co., Cleveland, announces that **George T. Motock** has been appointed director of research and development for the company's Cleveland and East Chicago, Ind., plants. Mr. Motock was previously associated with the Bureau of Mines, Battelle Memorial Institute and Republic Steel Corp.

Thomas C. Bradford, who has been associated with The Anderson Oil Co., Portland, Conn., since 1938, has been appointed field technical engineer for the company.

KEEP ARCOS IN MIND

FOR WELDING AND CUTTING STAINLESS, ALLOY, AND NON-FERROUS METALS

ARCOS electrodes and bare wire for the fabrication of stainless steels, and the Arcos Oxyarc Process for cutting stainless and other metals are a combination that will lower costs, increase production, and satisfy customers.

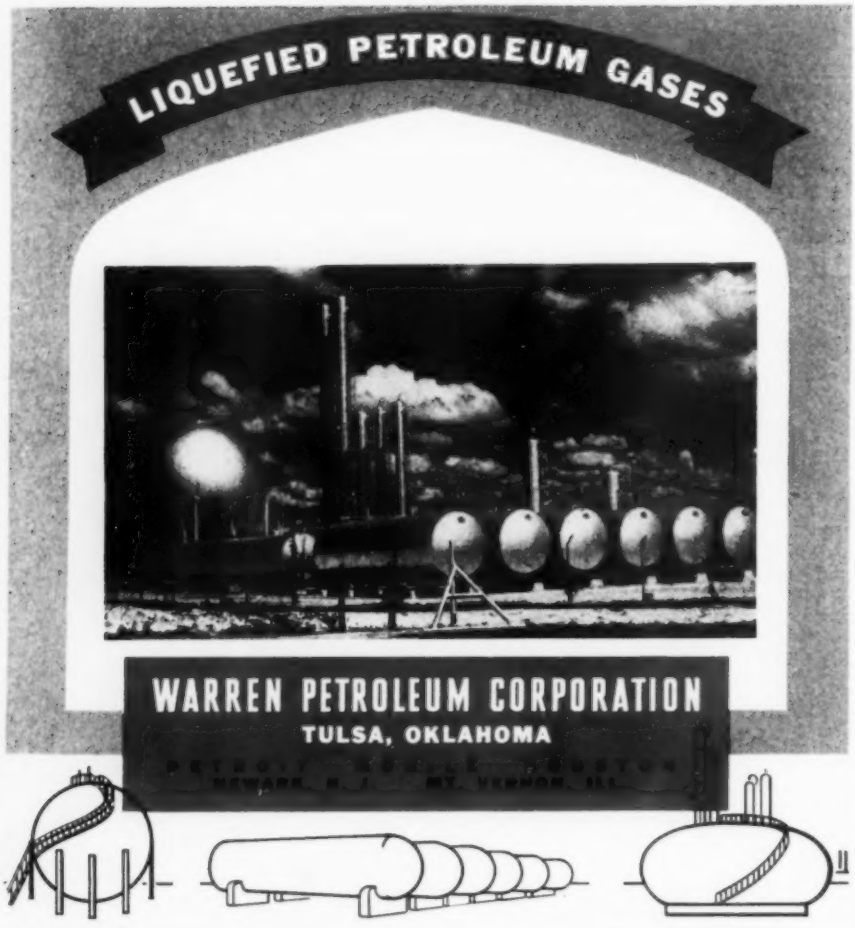
ARCOS

ARCOS CORPORATION • 306 GULF BUILDING, PHILA. 2, PA.

STAINLESS AND ALLOY WELDING ELECTRODES

and OXYARC PROCESS FOR CUTTING METALS

THE QUALITY NAMES IN ALLOY



IT WAS POOR STEEL...
that helped stock the world's richest locker*

* Davey Jones' Locker — tomb of dead ships, and fabulous treasure. Much of this tragic waste resulted from sloppy heat treating of ships' chains, cables, brackets, bulkheads, and other vital steel parts that failed under stress.

Science WORKS WONDERS WITH YOUR STEEL AT LAKESIDE!

This requires ideal conditions, complete modern facilities—metallurgical and mechanical. It's a big order, but Lakeside steadfastly refuses to obstruct Science by prejudice or inadequate equipment. Thus, your bar stock, forgings, castings, your rough or finished parts of assorted sizes and shapes, all receive the proper scientific treatment.

OUR SERVICES:

Electronic Induction Hardening, Flame Hardening, Heat Treating, Bar Stock Treating and Straightening (mill lengths and sizes), Annealing, Stress Relieving, Normalizing, Pack, Gas or Liquid Carburizing, Nitriding, Speed Nitriding, Aerocasing, Chapmanizing, Cyaniding, Sand Blasting, Tensile and Bend Tests.

THE *Lakeside Steel Improvement Co.*

5418 LAKESIDE AVE., CLEVELAND 14, OHIO HENDERSON 9100

Mg-Ce-Zr Alloys*

DEVELOPMENT of a magnesium-base casting alloy having good creep resistance came about because the standard magnesium-aluminum alloys are particularly poor in this respect, comparing quite unfavorably with aluminum alloys. The latter are therefore usually favored for stressed parts at elevated temperatures, such as crankcases of internal combustion engines, despite their greater weight.

The investigation centered on alloys based on magnesium and cerium (since it had been known for some time that these alloys in the wrought form possessed good creep resistance), and included not only a number of binary magnesium-cerium alloys but also magnesium-cerium alloys with various additions, principally zirconium. The cerium was added in the form of *mischmetall,* which incidentally was obtained from more than one source during the investigation. No attempt was made to distinguish between cerium and the other metals of the rare-earth group found in *mischmetall;* however, no evidence was found during the investigation to suggest that significance was to be attached to the proportions of the different rare earths.

It was found that the binary alloys could be successfully cast in sand molds with no tendency to hot crack, castings of complex design being readily produced to the highest standards of quality. Radiographic inspection consistently showed no streaky manifestations of microporosity commonly encountered with magnesium-aluminum alloys. On the other hand, the mechanical properties of the binary alloys were poor, only 7600 psi. proof stress (0.1%), 13,000 psi. ultimate tensile strength and 1% elongation being obtained on sand-cast standard pattern test bars of a 3% cerium alloy. Superheating the metal before pouring, or heat treating the castings, did not improve these properties.

Zirconium was added to the binary alloys in the hope that its powerful grain-refining power would effect some improvement in strength and ductility. *(To p. 270)*

*Abstracted from "Magnesium-Cerium-Zirconium Alloys", by A. J. Murphy and R. J. M. Payne, *Engineering*, June 6, 1947, p. 485-487.

GA ALLOYS THE QUALITY NAMES IN ALLOY FOR HEAT CORROSION ABRASION X-ite

THE FIGHTING IRISH SAY IT WITH MUSIC

"Faith," says Annie Gavin, "a pity to thim as thinks o' the 'Fightin' Irish' as a part Polack ball team, an' no disrespect to thim champeens intended," says Annie Gavin drawing three dark ales with one flip o' the tap. "All Irish is born fighters, but the fightenest of them all, the 'Wild Irish', came from South Boston, —not Dublin or even Cork, and make no mistake about that. These boys from Southey even cart trouble to the quiet peace lovin' city o' Cork." And three flips and twelve glasses later — "Take Pat McDonald, and him the big steel man, takin' his beautiful daughter to 'rib' the Colleens, —huntin' up Protestants to pick on in Cork, and the Saints preserve me if it ain't the truth I'm tellin'. Why, with Pat on the island thim poor Protestants were lockin' their Belfries clear up to Belfast."

Legends have been born and have flourished in Annie Gavin's Tavern. Concern for Irish Protestants was a new angle. Curiosity propelled us to the offices of "P. F. McDonald & Co. —Iron & Steel Mills — Boston, Mass., U.S.A." where our old friend Pat stoutly maintained that he went to Cork brimming with good-will toward all men, and that his gracious gesture with music was misunderstood. But it was not until Pat's daughter, Ann Marie (gracious and charming beyond the legend, drinking ginger ale on New Year's Eve), confirmed every detail so that we could give you the story.

Pat and daughter in the City of Cork last August during their visit to Ireland were interested in seeing the Bells of Shandon. These bells, eight of them, are in the tower of St. Ann's Church, a Protestant Church—a Church of Ireland affiliation. The City of Cork is Catholic, at least 99%, plus.

They climbed to the bell ringer's platform. The bell cords, eight of them, cover the range of the scale, but instead of proceeding from left to right, as do the notes on the piano, these cords start with the "do" on the right-hand side and run right to left. Pat is a pianist and while the others ascended the tower to see the bells, Pat mollified the attendant. As the party ascended, Pat started to play BELLS OF ST. MARY'S and BELIEVE ME IF ALL THOSE ENDEARING YOUNG CHARMS and caused quite a sensation with his daughter, who, she says, never fails to marvel at the right time.

After Pat had finished the second piece, he broke into THE WEARING OF THE GREEN. When he got half-way through the WEARING OF THE GREEN, the attendant broke into a sweat and grabbed Pat. "Ye can't do that, sa'r," he protested. "We can't be offendin' our Catholic friends a-playing 'Harp music on the bells o' this Protestant Church, — not to mention me gettin' sacked by the Rector. — I've got young'uns to feed, sa'r." At this point Pat expressed true Irish compassion, although he felt physically able to control the situation. "I did not want to see any fellow musician in trouble."

The Bell Ringer explained that seven years ago an English Colonel visiting the church had given him ten shillings to play GOD SAVE THE KING. That night, ninety-two windows were broken in the church. He was taking no more chances.

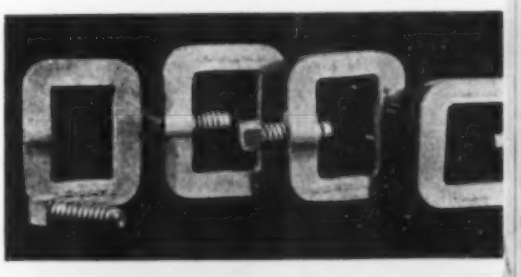
Pat says: "I felt good about the matter anyway because I am of Irish blood, my grandfather having been born in Cork, and I was returning to play THE WEARING OF THE GREEN in a Protestant church for the edification of the Catholics of Cork. We next visited a Catholic church, and we all said a prayer for the enlightenment of the Bell Ringer of St. Ann's."

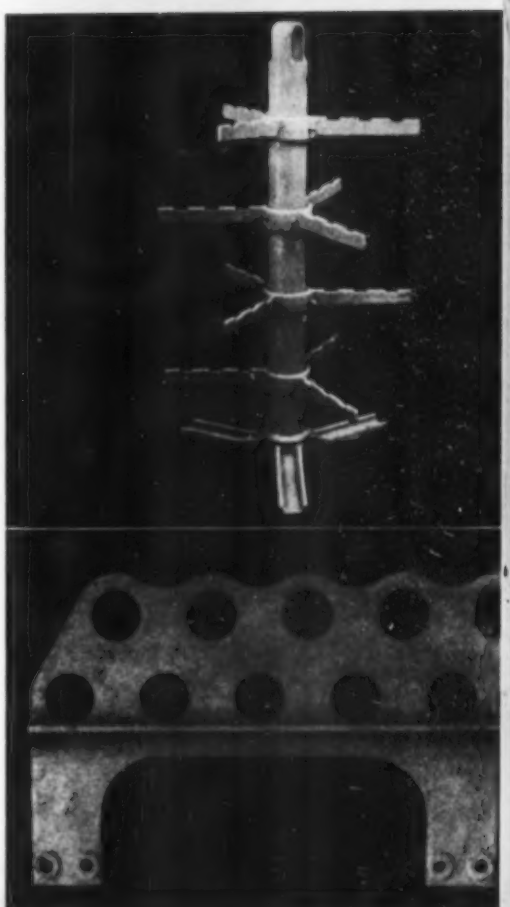
We expect to return to the tavern and set Annie straight that Pat really returned to Cork as a messenger of tolerance and peace.

We've promised Pat that on our next trip to Ireland we will make a stab at playing "Rock of Ages" on the Bells of the Cork Cathedral — but first we want to borrow a tank and a helicopter.

P.S. This is an advertisement, believe it or not, of General Alloys Company, Boston, Mass.

Pat McDonald and Ann Marie





THE FOOTSTEPS OF GENERAL ALLOYS MARK THE PATH OF AN INDUSTRY

DURASPUN

23 FEET of a 19 INCH *Centrifugally* CAST "CARTRIDGE"

It's alloyed to meet a highly corrosive condition. It's centrifugally cast to give it the higher strength and greater metal density to meet a tough structural requirement. It's typical of what we can do in our centrifugal casting department. In this case two sections were made and welded together.

May we suggest that if you have need for any high alloy pipe or tube ranging in diameter from 2½ inches to 24 inches and, depending on diameter, up to 15 feet in length, you look into our centrifugal casting service.

THE DURALOY COMPANY

Office and Plant Scottdale, Pa. • Eastern Office 122 East 41st Street, New York 17, N. Y.

Los Angeles & San Francisco KILSBY & HARMON

Chicago & Detroit F. B. CORNELL & ASSOCIATES

METAL GOODS CORP. St. Louis • Houston • Dallas • Tulsa • New Orleans • Kansas City

2-DU-1

Mg-Ce-Zr Alloys

(Cont. from p. 268) It was found that this refining ability was retained in the presence of cerium, and 0.5% zirconium added to the 3% cerium alloy led to considerably higher values for proof stress (12,000 psi.) and ultimate tensile strength (19,000 psi.).

The magnesium-cerium-zirconium alloys retain their strength well at elevated temperatures, as shown in short-time tensile tests. Sand-cast test bars of the 3% cerium, 0.65% zirconium, alloy gave values for ultimate strength of 18,500 psi. when tested at 250° C. (450° F.). In creep tests carried out at 200° C. (390° F.) the magnesium-cerium alloys, with and without additions of zirconium, show to great advantage when compared with the standard magnesium-aluminum alloy, Elektron A8 (7.9% Al, 0.4% Zn, 0.3% Mn, 0.25% Si, balance Mg). Creep tests at 200° C. on a 1.81% cerium alloy and on Elektron A8 using an applied stress of 4500 psi. showed the magnesium-aluminum alloy to yield continuously at a "fast rate" (not reported) throughout the duration of the test, whereas the magnesium-cerium alloy suffered no appreciable deformation after the first 50 hr.

When tested at 9000 psi. the magnesium-aluminum alloy failed after 48 hr. at 200° C., having extended 15%; the magnesium-cerium alloy remained unbroken but showed an extension of 3.9%. Comparative tests between an R.R.-50 aluminum alloy★ and a 2.67% cerium, 0.4% zirconium, magnesium alloy showed the creep rate of both materials between the 100 and 200th hour to be less than could be detected with the equipment used; furthermore, the total strain at the end of the test period was approximately the same for the magnesium and the aluminum alloys, in spite of a marked difference in the strains produced by the initial application of the load in the cold (due to the large difference of elastic moduli in aluminum and in magnesium).

The addition of other elements (such as calcium, zinc, and silver) was investigated and found to offer no improvement on the good high-temperature properties imparted by the cerium alone.

★1.2% Cu, 1.3% Ni, 0.1% Mg, 1.1% Fe, 0.18% Ti, 2.2% Si, bal. Al.

Buehler . . .

. . . OFFERS A COMPLETE LINE OF EQUIPMENT FOR THE Metallurgical Laboratory

Buehler specimen preparation equipment is designed especially for the metallurgist, and is built with a high degree of precision and accuracy for the fast production of the finest quality of metallurgical specimens.

1. No. 1315 Press for the rapid moulding of specimen mounts, either bakelite or transparent plastic. Heating element can be raised and cooling blocks swung into position without releasing pressure on the mold.

2. No. 1210 Wet power grinder with 3/4" hp. ball bearing motor totally enclosed. Has two 12" wheels mounted on metal plates for coarse and medium grinding.

3. No. 1000 Cut-off machine is a heavy duty cutter for stock up to 3-1/2". Powered with a 3 hp. totally enclosed motor with cut-off wheel, 12" x 3/32" x 1-1/4".

4. 1505-2AB Low Speed Polisher complete with 8" balanced bronze polishing disc. Mounted to 1/4 hp. ball bearing, two speed motor, with right angle gear reduction for 161 and 246 R.P.M. spindle speeds.

5. No. 1700 New Buehler-Waisman Electro Polisher produces scratch-free specimens in a fraction of the time usually required for polishing. Speed with dependable results is obtained with both ferrous and non-ferrous samples. Simple to operate—does not require an expert technician to produce good specimens.

6. No. 1410 Hand Grinder conveniently arranged for two stage grinding with medium and fine emery paper on twin grinding surfaces. A reserve supply of 150 ft. of abrasive paper is contained in rolls and can be quickly drawn into position for use.

7. No. 1400 Emery paper disc grinder. Four grades of abrasive paper are provided for grinding on the four sides of discs, 8" in diameter. Motor 1/3 hp. with two speeds, 575 and 1150 R.P.M.

8. No. 1015 Cut-off machine for table mounting with separate unit recirculating cooling system No. 1016. Motor 1 hp. with capacity for cutting 1" stock.

THE BUEHLER LINE OF SPECIMEN PREPARATION EQUIPMENT INCLUDES . . . CUT-OFF MACHINES ● SPECIMEN MOUNT PRESSES ● POWER GRINDERS ● EMERY PAPER GRINDERS ● HAND GRINDERS ● BELT SURFACERS ● MECHANICAL AND ELECTRO POLISHERS ● POLISHING CLOTHS ● POLISHING ABRASIVES

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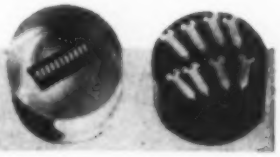

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Casting Wheels of Copper Alloys*

INVESTIGATIONS were carried out to determine the influence of rotational speed, casting temperature, and mold design on the soundness, microstructure, segregation and properties of 10-in. wheels both statically and centrifugally cast from five different alloys.

The alloys fell into two groups. The first comprised an aluminum bronze and a high-tensile brass having a narrow freezing range — 35 and 10° F., respectively — and normally free from any tendency to form dispersed microporosity. The second group consisted of a series of tin bronzes — a phosphor bronze, a gun metal and a leaded gun metal having a broad freezing range (625, 115 and 115° F., respectively) — showing the usual high tendency for such alloys toward general dispersed porosity.

The wheel that was cast was 10 in. in outside diameter with 2.5 in. rim joined to the hub by five arms or spokes, which were ⅝ in. thick.

The aluminum-bearing alloys when statically cast in sand molds having a central runner with heads over each junction of an arm and the rim (the wheel being in a horizontal position) were completely sound. When statically cast without the heads but with all other conditions the same, these alloys developed gross internal voids and surface cracks at the junctions of the arms and the rim. When this latter arrangement was centrifuged about a vertical axis, the cracks changed to surface shrinkage markings and finally disappeared at the highest speed used experimentally (780 r.p.m., corresponding to 50 psi. centrifugal pressure at the rim), while the voids continuously decreased until at the highest speed they were reduced to small subsurface holes. The density and mechanical properties of the centrifugally cast wheels did not change much with increasing rotational speeds since these alloys do not form general dispersed porosities. (The localized gross voids were avoided in taking density or tensile samples.) *(Cont. on p. 274)*

*Abstracted from "The Centrifugal Casting of Copper Alloy Wheels in Sand Moulds", by O. R. J. Lee and L. Northcott, *Journal* of the Institute of Metals, V. 73, Part 8, 1946-1947, p. 491-520.

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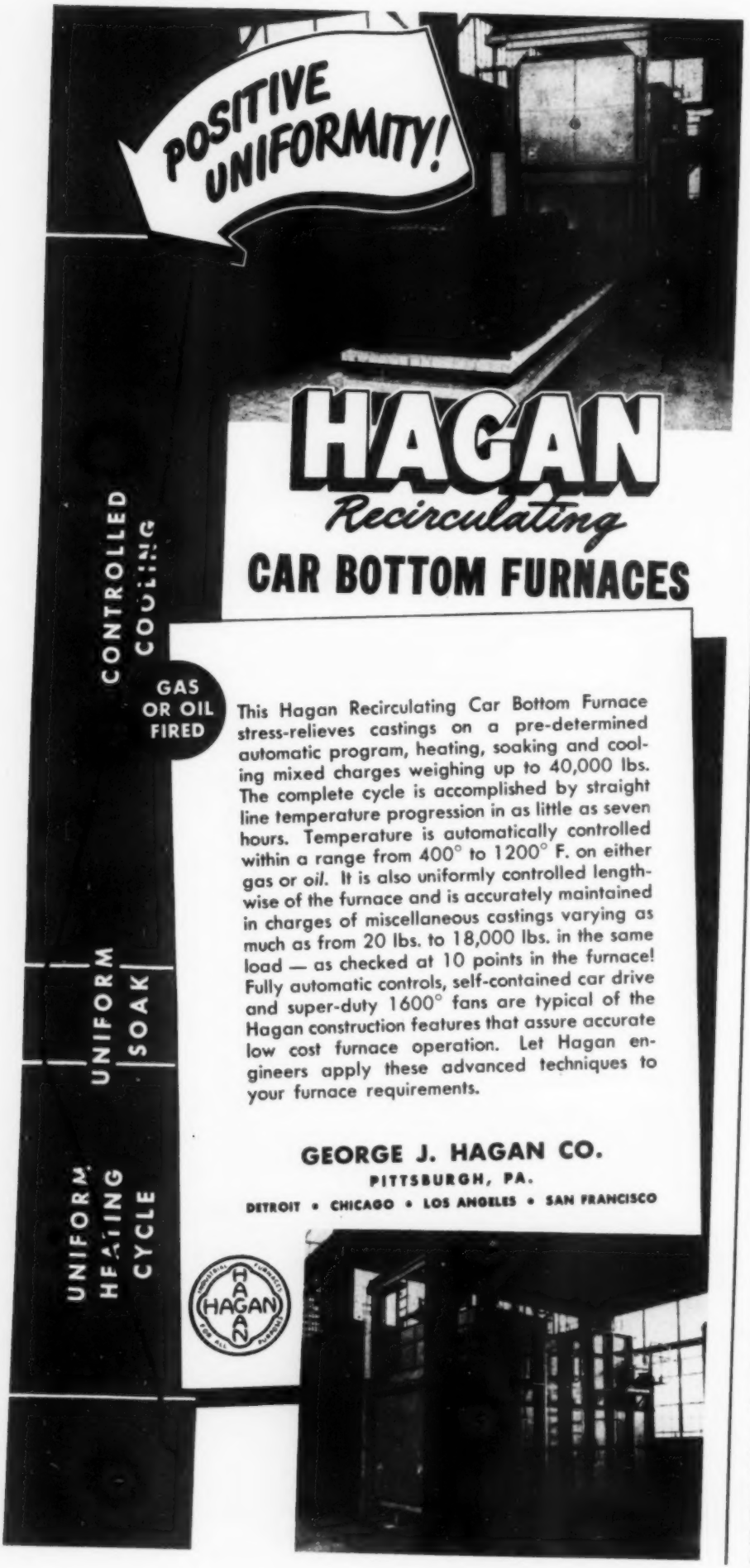
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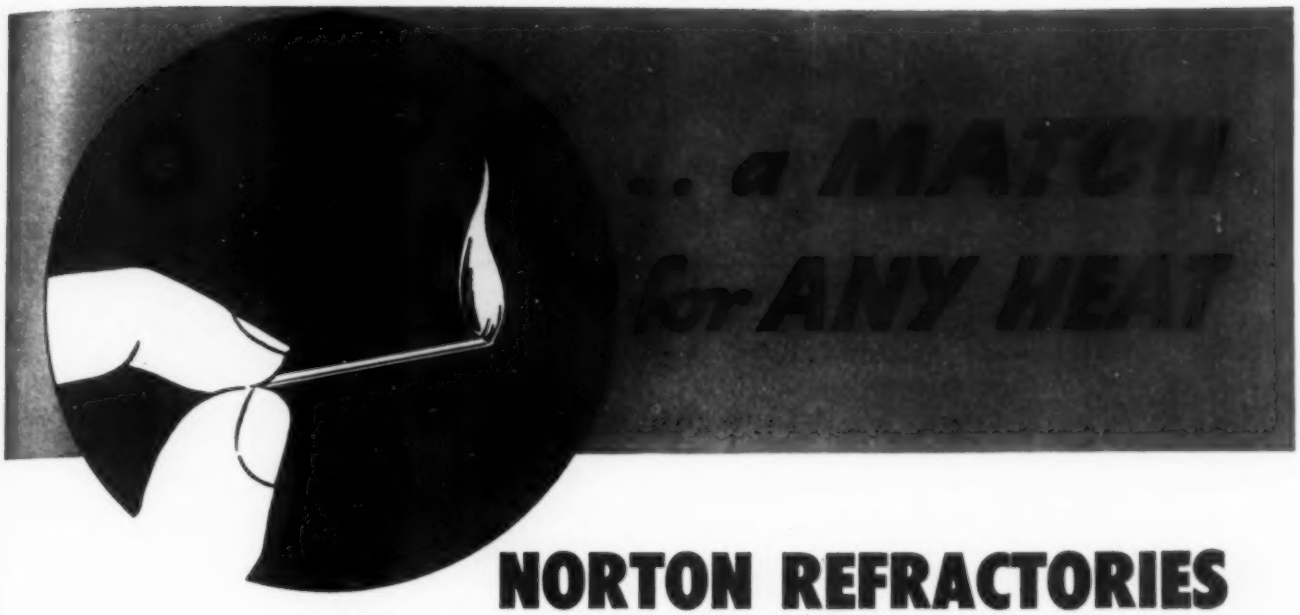
Casting Wheels

(Cont. from p. 272) The only role which increased centrifuging played, therefore, was the elimination of localized voids (which properly designed static castings did more efficiently). There was no adverse segregation or separation of the constituents under high rotational speeds.

The situation was quite different with the tin bronzes in the second group. When statically cast with risers, these alloys showed dispersed unsoundness below the feeding heads. Without the risers, static casting produced fairly sound wheels with general dispersed porosity, as indicated by etching and density. The density of these alloys when centrifugally cast at even low speeds was considerably increased. At higher speeds the rim of the wheel continued to show slight increases in density but the arms showed slight decreases in density. Because of this elimination of dispersed porosity these alloys can be centrifugally cast with considerable improvement in mechanical properties.

The tensile properties do not improve continuously with centrifuging speed, however, since the eutectoid forms an intergranular network of brittle constituent under the influence of centrifuging. This effect is exaggerated by low casting temperatures. Properties will continue to be improved as long as the beneficial effect of improved density outweighs this microstructural effect. For this reason the best mechanical properties were obtained at moderate rotational speeds. Annealing the centrifugal castings to dissolve the eutectoid resulted in greater improvement in mechanical properties than in static castings (where porosity still had an effect), the improvement being greatest at the highest speeds.

A design of casting that can be obtained almost sound by static casting without feeder heads will only require a fairly small pressure (speed of rotation) to make it sound as a centrifugal casting, but a casting in which directional solidification toward a central runner is inadmissible will prove incapable of improvement by centrifugal casting. This generalization proved to be true in the present study. When the *(Cont. on p. 276)*



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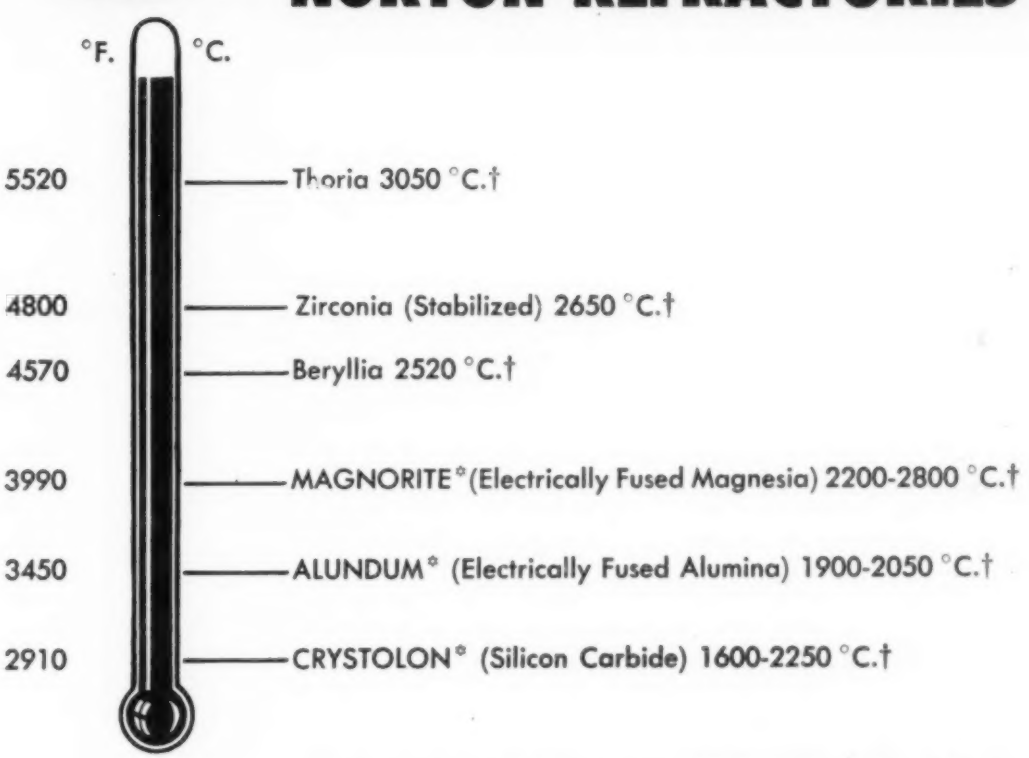

† Norton Pure Oxide Refractories and Refractory Grain can be used at considerably higher temperatures than can the bonded shapes.

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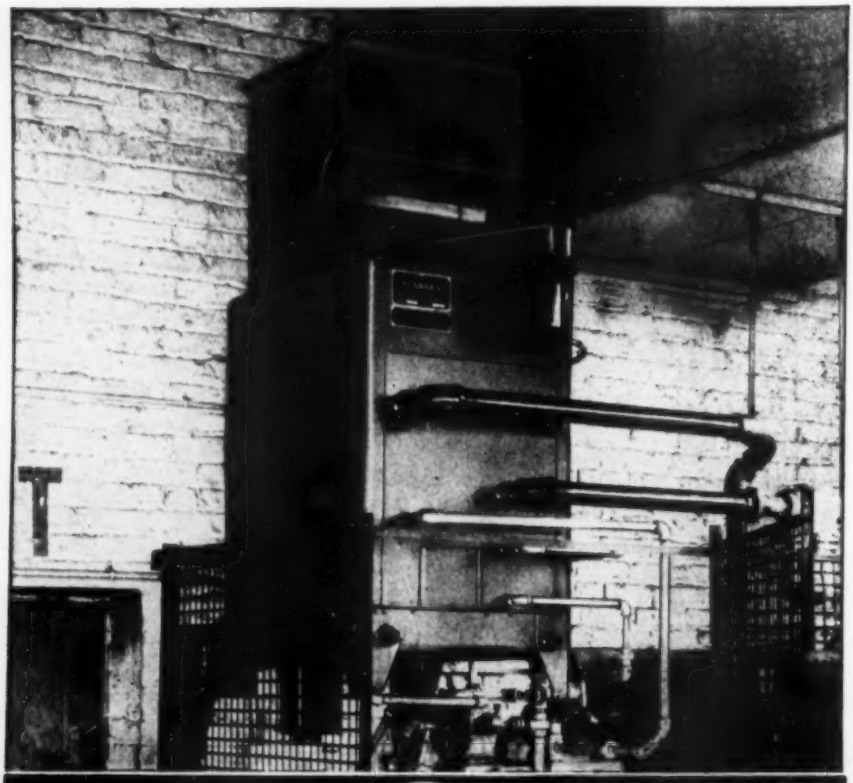

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Casting Wheels

(Starts on p. 272) thickness of the spokes was reduced from ⅝ in. to ¼ in., castings were highly defective in all alloys. The rapid freezing of the arms restricted the flow of feeding liquid to the rim, and the junctions were often completely penetrated by voids. A minimum ratio of spoke cross section to rim volume of 1 to 10 would be a basis for design of wheel-type castings for copper alloys.

Protective Coatings*

THE WORD "corrosion" is derived from the Latin, *rodere*, to gnaw, and well expresses the processes of surface degradation whereby metals exposed to atmosphere are converted to oxides and salts of the type in which they occur in nature.

The reactions involved in these processes are electrochemical in character — that is, they involve the operation of electrolytic cells. In the presence of moisture, metallic ions go into solution at areas on the metal surface which thus become anodes, and hydrogen ions are discharged at other areas which become the cathodes of these cells.

The *rate* of corrosion depends upon the rate of diffusion of metal ions from anodic areas and hydrogen atoms from the cathode surfaces. Accumulation of these products at the electrodes results in polarization of the cells and practical cessation of corrosion. In particular, effective anodic polarization may be induced by the presence in the environment of substances — such as chromates, phosphates, or silicates — which produce highly insoluble compounds with the metal. This inactivation of anodic areas converts the entire surface to coatings which, so long as they remain intact, protect the metal from corrosion.

In corrosion processes such as oxidation or *(Continued on p. 278)*

*Author's summary of two talks given in March 1947, at Western Metal Congress, Oakland, Calif., on "Recent Developments in Protective Coatings", by R. M. Burns, chemical director, Bell Telephone Laboratories.

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Protective Coatings

(From p. 276) tarnishing in the absence of appreciable amounts of water vapor, the reaction is again electrolytic in character. The metal surface as a whole acts as the anode against a cathode which initially is probably a monomolecular layer of oxygen, sulphur, or other nonmetallic element in contact with the metal surface. In the operation of this electrolytic cell, metal ions and electrons leave the metal surface and migrate into the metal-environment interface. The electrons ionize the nonmetallic elements, converting them into ions, and there is built up a lattice of corrosion products which becomes a film of increasing thickness. Such processes of corrosion are controlled by the resistance of this structure to the diffusion of electrons, or ions, or both.

There are two general methods for the control of corrosion: Either a noncorrosive environment may be provided in which there is no opportunity for corrosion, or some barrier may be provided capable of protecting the metal surface from corrosive attack. Of the first method, control of humidity and atmospheric pollution, and deaeration of boiler waters may be cited as examples. The second method, of far greater practical importance, depends upon either the protective films naturally formed on many nonferrous metals and corrosion resistant alloys, or the use of paints or other organic coatings or vitreous enamels.

The use of copper and lead sheets for roofing depends upon the protective qualities of the films of corrosion products which develop upon these metals. More recently the favorable experience of aluminum and certain of its alloys has led to their use as roofing materials. Protective coatings, such as nickel and chromium which are cathodic to steel, depend upon these superficial films for their protective quality. Zinc, on the other hand, in addition to its natural resistance provides cathodic protection to steel. Extensively used during the war, chromate dipping of zinc coatings markedly improves their resistance to tropical exposure.

Heavier undercoatings of nickel now being applied in nickel-chromium finishes should give improved

performance. Still heavier coats of nickel are now being used as tank car linings, and should be of value for such commodities as wine, shipped in bulk.

The vast and diversified developments in the plastics field in recent years has yielded many new and greatly improved organic coatings. Their quality stands in contrast to the ordinary oleoresinous paints of a generation ago, or the primitive coating of beeswax which is said to have preserved the suspension bridge over the Feather River near Oroville, Calif., for 60 years.

While the alkyd type resins continue to be the basis of the largest proportion of industrial finishes, many of the new plastic materials combining a variety of properties are now used. Modifications of the alkyds with maleic and urea or melamine are used in finishing household products.

The vinyl resins, owing to their freedom from odor, taste and toxicity, are finding increasing applications in the food and chemical industries, and are being used by the Army and Navy to spray "cocoons" of plastic film for the protection of equipment going into storage. Suspensions of vinyl resins in organic solvents permit the application of heavy coatings which, after baking, become continuous films.

Combinations of chlorinated synthetic rubber with phenolic resins have been found particularly suitable as finishes for concrete floors. Nitrocellulose and ethyl cellulose lacquers of high solid content have been developed and are finding increasing applications.

Mullite and Al_2O_3 Refractories*

IN ORDER to determine what happens to certain refractories at temperatures above 3000° F. (1650° C.) specimens about 1½ x 2½ x 4½ in. were cut from commercial brick. These specimens were placed on 99% alumina brick stools —except the zircon, which was set

(Continued on page 280)

*Abstract of "Properties and Uses of Mullite and Pure Alumina Refractories", by G. B. Remmey, Richard C. Remmey Son Co. Paper before the American Ceramic Society, refractories division, October 1947.

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Mullite and Al_2O_3

(Continued from page 279)

on zirconia brick. Pieces then were heated successively to 3100, 3300, 3350, 3400, and 3500° F. (1700 to 1925° C.). Heatings at 3500° F. were for 15 min. Specimens were held 4 hr. at all other temperatures; if it survived one treatment, the same piece was heated to the next higher temperature. Results are summarized in the table.

At 3100° F. (1700° C.) only the kaolin brick showed the effect of the heat treatment; it had shrunk a little. At 3300° F. (1825° C.) the regular mullite brick "folded up". At this temperature some reaction had started between zirconia and 99% alumina brick. At 3350° F. (1850° C.) the "low" alumina brick, such as the 91%, was very soft; mullite brick having a bond "built up" like that in an Indian kyanite brick was satisfactory at this temperature. At 3400° F. (1875° C.) the zirconia-alumina reaction became pronounced; the zircon brick fell against a high-alumina specimen and considerable reaction occurred. Crystalite A melts at about 3400° F., and a brick heated to that temperature may have one end melted and the other end unaffected. There was little reaction between the zircon and zirconia at 3400° F.

At 3500° F. (1925° C.) the 99% alumina and the "vitrified" alumina (98%) remained in good condition. The author stated that only a slight amount of silica or other fluxes damages alumina brick at 3500° F., whereas zircon reacts seriously with mullite and also with alumina at 3300° F. (1825° C.).

Some load-test data were given, based on the subsidence at 2950° F. (1620° C.) under load of 25 psi.:

Crystalite, regular	3.6%
Crystalite A	0.0
91% alumina	5.5
90% alumina	6.5
99% alumina	5.5
"Vitrified" alumina	3.0
Zircon	+0.7

Appearance of Brick After Reheat

Refractories	3100° F.	3300° F.	3350° F.	3400° F.	3500° F.
99% alumina *(a)*	Good	Good	Good	Good	Good
Vitrified alumina *(b)*	Good	Good	Good	Good	Good
92-93% alumina	Good	Good	Soft		
91% alumina	Good	Slumped	Slumped	Slumped	Soft *(c)*
90% alumina	Good	Slumped			
87-88% alumina	Good	Slumped		Slumped	
Crystalite *(d)*	Good	Good	Good		
Crystalite A *(e)*	Good	Good	Good	Slumped	
Mullite (regular)	Good	Slumped			
Mullite (vitrified)	Good	Good	Slumped		
Kaolin	Some effect	Shrank	Soft		
Zircon	Some effect	Good	Good	Good *(f)*	

(a) Pyrometric cone equivalent 42.
(b) 98% Al_2O_3, slip cast, 0.1% absorption.
(c) The 91% Al_2O_3 brick was set on a 99% alumina brick and they coalesced, as liquid from the 91% brick drained out and was absorbed by the 99% Al_2O_3 stool. The penetration was 2 or 3 in.
(d) Regular; pyrometric cone equivalent 39.
(e) Slip cast.
(f) Reacted with adjacent alumina brick.

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